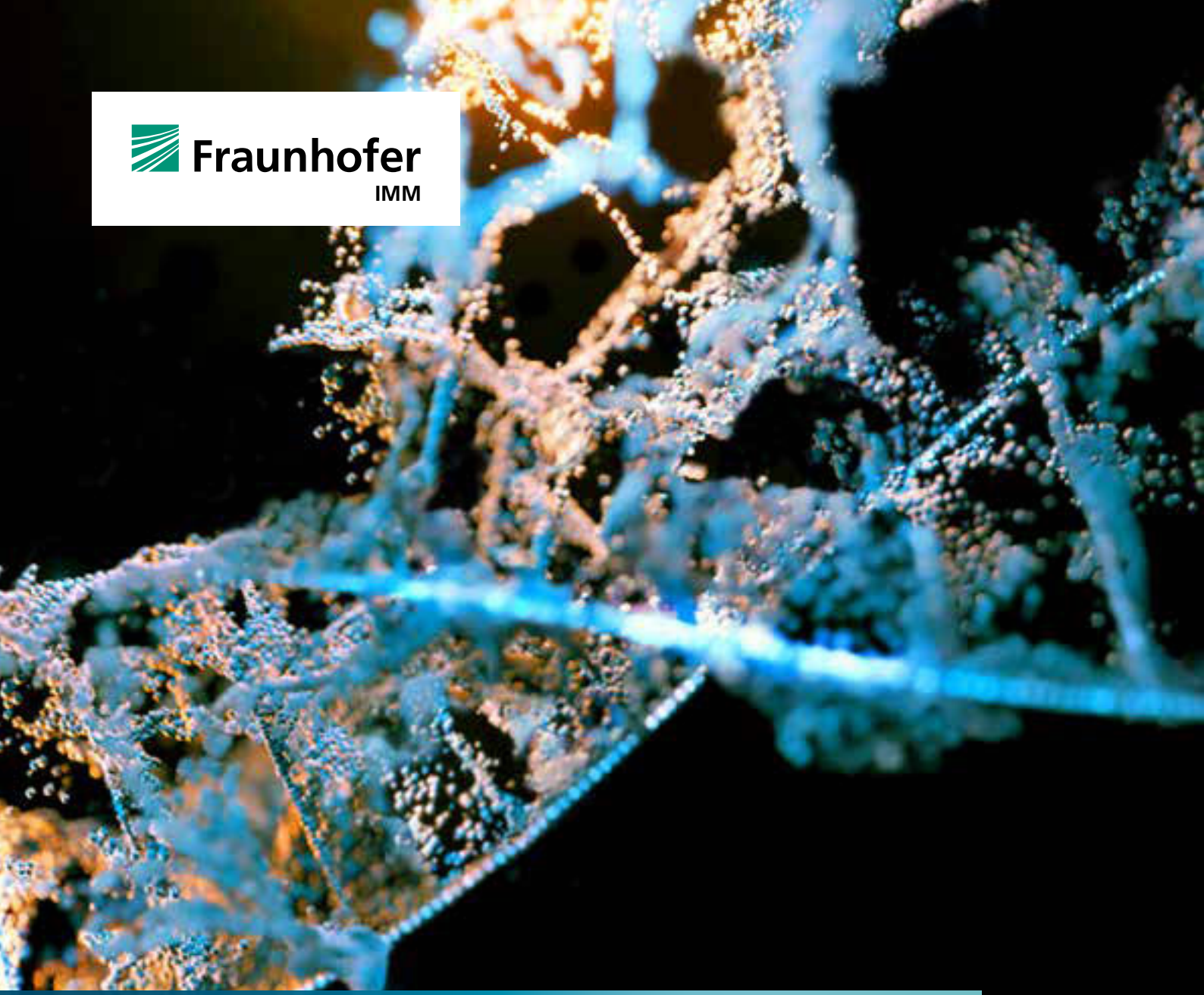

Fraunhofer IMM

Annual Report 2021/22: Responsible and Healthy Living

Making the Difference

Fraunhofer Institute for Microengineering and Microsystems IMM

Annual Report 2021/22: Responsible and Healthy Living

Making the Difference

Editorial Notes

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It is not enough to know – one must also apply. It is not enough to want – one must also do.«

Johann Wolfgang von Goethe

Editorial

Vulnerable supply chains, shortage of materials, pandemic threats, war versus energy transition, sustainability, economic growth and well-being are some of the ubiquitous buzzwords, much more, they appear to be antagonists that somehow make the goal of a responsible and healthy living more distant. This creates the challenge that an individual party is even less able to tackle on its own today than in the years before.

It is not without reason that there is an expectation among politicians and the general public that the major research institutions must assume their share of responsibility here in order to create viable solutions. As part of the Fraunhofer-Gesellschaft and even before we have been directly and indirectly devoting a large share of our working force to establish cleaner and more energy efficient processes and develop detection as well as production methods beyond existing limits. Highest accuracy at maximum possible speed and low space requirements at high functionality are suspected contradictions that determine our daily work.

But how are we doing that? To answer that question, let me briefly "draw" a picture: the rungs of the well-known DNA ladder are built by the four bases adenin, guanin, cytosin and thymin. The sequence of bases finally determines the order of amino acids in a protein and, thus, life. Fraunhofer IMM's building blocks of success are our very profound **competences with respect to materials, technologies, systems and engineering.** Combined in the right manner, they result in a versatile number of processes and devices allowing us to tackle at least some of the imminent challenges mentioned above to the extent that our resources allow us. We are working hard to make a difference to enable a responsible and healthy living. To quote the German poet Johann Wolfgang von Goethe: **"It is not enough to know - one must also apply. It is not enough to want - one must also do."**

Enjoy browsing for an overview of the work we have done over the past year!

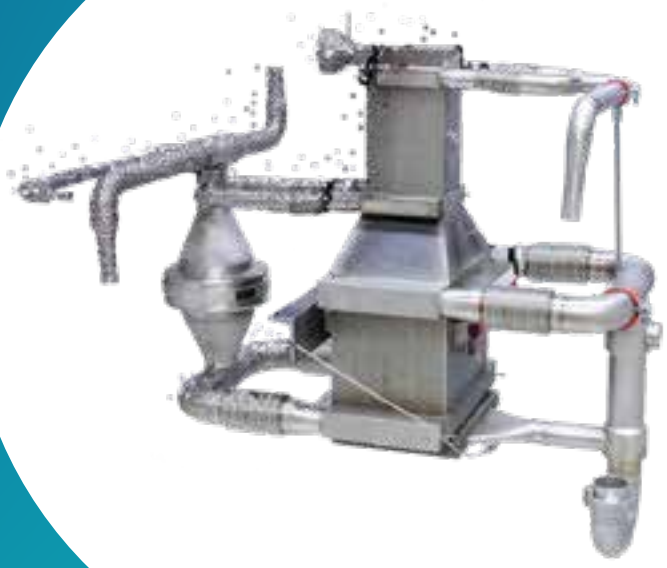
PROF. DR. MICHAEL MASKOS
EXECUTIVE DIRECTOR, FRAUNHOFER IMM

HOT TOPICS

According to the Sustainable Development Goal (SDG) Progress Report 2022 issued by the Economic and Social Council of the United Nations due to the persistent crisis situations "years, or even decades, of development progress have been halted or reversed" with respect to the efforts to realize the SDGs. Against all odds, such as the continuing pandemic, major supply-chain disruptions, policy uncertainties or astronomic price increases, decisive action has never been as urgent as it is today. The contribution of any single research institute seems marginal in the face of major challenges. But all these little steps will make the difference in the end. In a narrower or broader sense the majority of Fraunhofer IMM's projects is dealing with topics of high relevance for society.

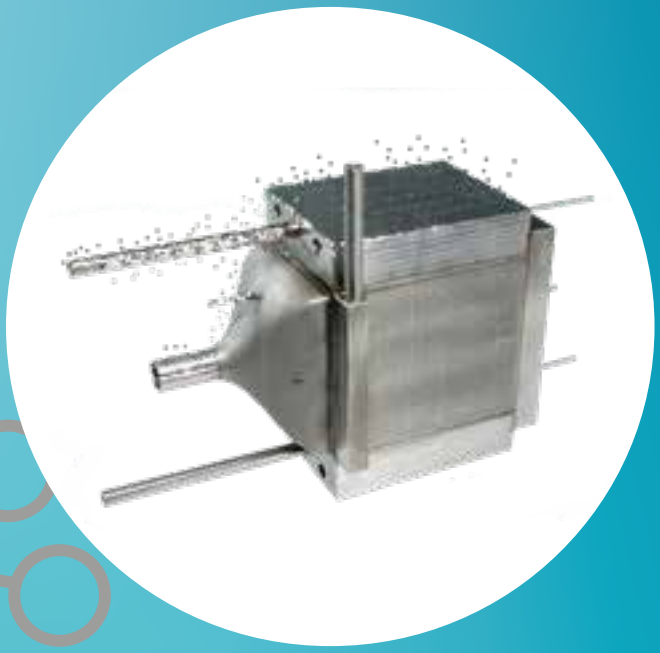
CLEAN ENERGY

This topic is being worked on across the business fields of energy and chemistry and it is, of course, partially linked to our sustainability efforts. Basically and simplified, everything revolves around alternative energy sources, the provision of hydrogen that is as green as possible and the avoidance of carbon dioxide emissions or its utilization. We target the following applications:



Hydrogen-based energy supply solutions

- combined heat and power unit for small to medium stationary solutions
- fuel processor solutions for powering maritime and agricultural vehicles, aircraft assistance, transport, and automotive
- auxiliary power units

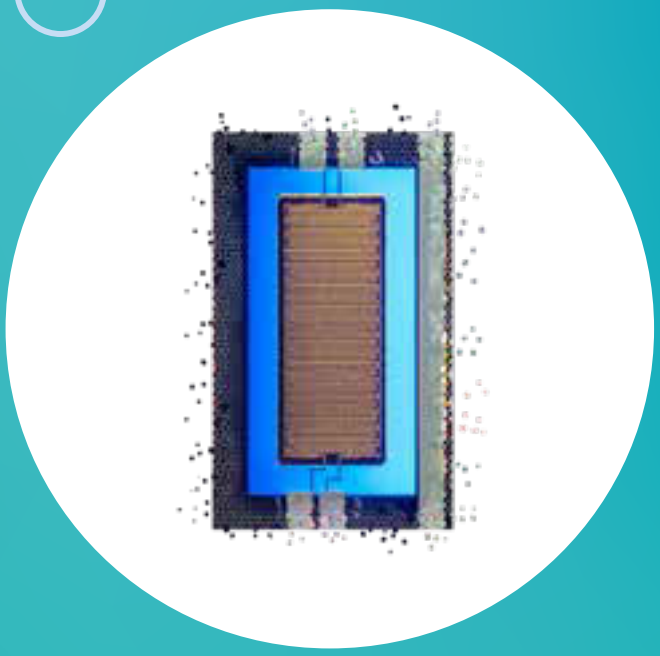


Power-to-chemicals

- renewable energy storage (methanation)
- biofuel production

Ammonia utilization

- powering deep sea vessels
- reducing carbon dioxide in industrial processes



Radiation monitoring

- Surveilling fusion experiments

SUSTAINABILITY

This topic is being worked on across all our business fields and it is partially linked to our clean energy and health efforts. Basically and simplified, everything revolves around reducing the environmental footprint of processes, increasing their safety and efficiency as well as the monitoring of critical process or environmental parameters. We target the following applications:

Process monitoring

- condition monitoring of process media
- monitoring of critical product parameters and real-time quality control
- leak detection in circuits

Environmental monitoring

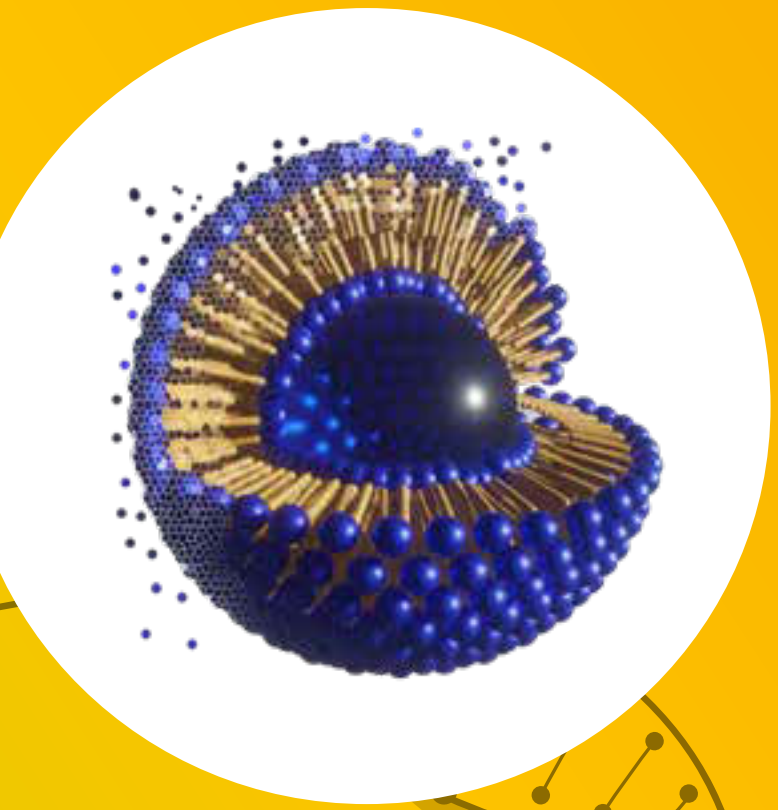
- high precision components for imaging spectroscopy monitoring climate and environmental changes
- air contamination control
- surveillance of water quality

Flow chemistry-based process innovation/intensification

- photochemical utilization of carbon dioxide
- electrification of chemistry
- reactive intermediates for pharmaceutical applications
- innovative processing regimes targeting fine chemicals, special chemicals, agrochemicals, …
- materials with tailor-made properties

Decentralized production concepts for chemicals

- multifunctional, compact, modular plant concepts and their installation in a container-like infrastructure
- innovatively manufactured reactors



Nanoparticle systems for therapeutic and diagnostic as well as industrial applications

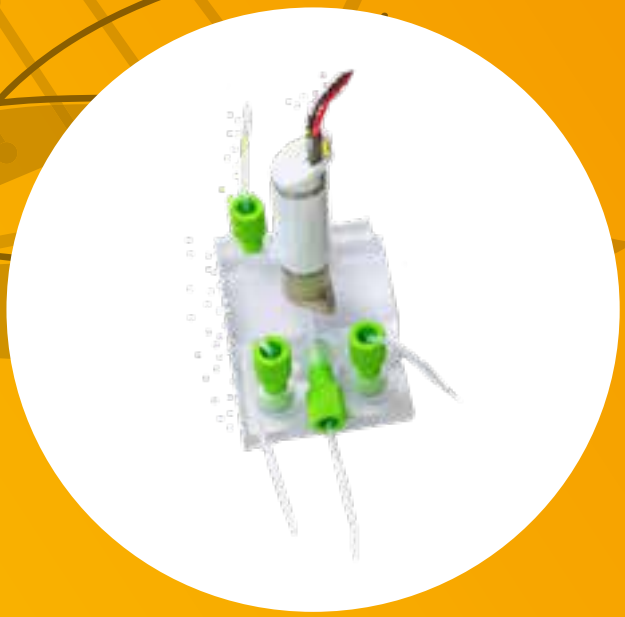
- targeted drug delivery
- encapsulation of sensory active ingredients, value adding substances and matrix components

Liquid biopsy and single cell analytics

- cancer diagnostics
- research for therapy development and monitoring of therapy success

HEALTH

This topic is being worked on across the business fields of diagnostics and chemistry and it is partially linked to our sustainability efforts. Basically and simplified, everything revolves around the isolation and detection of cells, microorganisms or pathogens for diagnostic, therapeutic or quality control purposes, the determination of their properties or the provision of active ingredients where needed with tailor-made properties. We target the following applications:



Biological media analysis

- determination of microorganisms in industrial media
- quality control of food and in food production processes

Infection diagnostics

- PCR-based diagnostics of infectious diseases
- pandemic control
- fast sepsis detection

FLAGSHIP PROJECTS

In this section we continue to present the progress in some of our flagship projects, one for each of the business fields. These projects are of particular importance as they are outstanding representatives for the capabilities of microsystem technology allowing to make a real difference in real-world applications.

Liquid Biopsy

THE GOAL: Analyzing a variety of relevant biomarkers from one single standard blood sample giving access to novel diagnostic procedures.

THE STATUS: The microfluidic platform was further exploited to isolate circulating tumor cells (CTCs) from head and neck cancer patients in two German university hospitals. Single cell analysis of the isolated cancer cells allowed for differentiation of epithelial and mesenchymal-like cell types. These findings are a first step to correlate the invasiveness of an individual cancer pathology with the CTC count based on this liquid biopsy demonstrator. An encompassing understanding of tumor cell heterogeneity can not only be used to predict disease outcome but also to suggest potential personalized therapies.

The in-depth characterization of the enrichment parameters and flow properties for an improved cell isolation, also showcasing early results of patient sample analysis were published in peer-reviewed journals. The visibility of our studies was used to gain interest in collaboration at academic partners. In the future, the liquid biopsy platform is to be compared to commercially available isolation technologies at the interface of preclinical and clinical research.

Due to the flexibility of the platform, the isolation of other rare cells in body fluids or tissue suspensions to study immunology or batch quality control in medicinal product manufacturing is subject of additional expert discussions.

The basic information: https://www.imm.fraunhofer.de/en/applications/liquid-biopsy.html

Pilot Plant for the Continuous Grignard Synthesis

THE GOAL: Flexible provision and processing of reactive intermediates in a resource efficient way and at a scale that allows to address chemical and pharmaceutical production.

THE STATUS: The Work within the last year has focused on strengthening the cooperation with an industrial partner for the establishment of a pilot plant at their site with particular emphasis on health and safety regulations and engineering specifications that have to be complied with.

Furthermore, the piloting set-ups existing at Fraunhofer IMM have been moved to the dedicated laboratory in the new building and have been brought into operation there. This now allows for a combination of reactive organometallic intermediate formation with a direct follow-up step on pilot level throughputs.

In order to strengthen and broaden the product portfolio accessible with the technology, the reactor concept has been further tested and expanded with a broad range of Zn organometallic reagents complementing the already well established Grignard reagent formation. The highlight in this field was the proven easy scale-up of a number of Zn organometallics to throughputs of up to 18 l/h.

The basic information: https://www.imm.fraunhofer.de/en/innovation-fields/reactive-intermediates.html

Power-to-Chemicals – Microreactor-based Electrolysis

THE GOAL: Green synthesis routes starting from renewable raw materials and using sustainably generated electric current as reagent for a sustainable production of chemicals.

THE STATUS: Our flexible and scalable electrochemical microreactor concept has been adjusted to the specific needs of the Kolbe electrolysis of carboxylic acids to fatty alkanes as a reference process. The starting material carboxylic acids thereby can in principle be obtained from biomass and represent in general a platform chemical to obtain solvents, fuels, fine chemicals, lubricants, and polymers. Intensive lab scale investigations have been performed to optimize the process in view of yield, selectivity and energy efficiency. For this, current density, residence time, used cell configuration, and electrode materials have been varied in the experiments. Based on the obtained optimized process parameters, a pilot plant installation has been designed to investigate further central process aspects for a later industrial uptake, like long time operation, the implementation of a recycling loop for the non-used starting materials in the electrolyte solution and scale-up. A basic pilot plant installation has been erected and will be further modified to increase throughput rate step by step. Envisioned is to increase the number of electrochemical cells operated in parallel in a joint reactor housing up to 20 cells corresponding to a production capacity of about 3 kg of product per hour for the reference process. Up to date the increase of up to 4 cells has been successfully validated, i.e. a first scale-up of the process to higher throughput by parallelization without loss in performance. This represents an important step on the way to address industrial relevant throughputs.

The basic information: https://www.imm.fraunhofer.de/en/innovation-fields/electrochemical-synthesis.html

Methanol as Hydrogen Carrier

THE GOAL: Construction and operation of a methanol reformer in the 100 kW scale as hydrogen source.

THE STATUS: Methanol is an excellent hydrogen carrier, which can be transported much easier compared to compressed and liquefied hydrogen and is available even at fuelling stations in some areas of the world already. It can be produced from athmospheric carbon dioxide and renewable hydrogen, thus creating net zero carbon dioxide emissions. To be able to utilize the contained hydrogen, the methanol can be converted back to hydrogen with reformer technology at highest efficiency, which is one of the core competences of the Energy Division at IMM. The hydrogen made available by these means can be fed to certain types of fuel cells directly or further purified e.g. by pressure swing adsorption.

We have developed unique catalyst and reactor technology for methanol reforming which is much better suited for mobile applications compared to alternative solutions. Through the significantly higher activity of the self-developed patented catalyst technology, catalyst coatings can be applied similar to what is known from automotive exhaust cleaning – avoiding catalyst attrition-related upsets of the reformer system.

Having demonstrated the feasibility of this unique approach in a multitude of systems of increasing power equivalent (100 W – 5 kW – 35 kW) IMM is now realizing a methanol reformer with 100 kW power equivalent which can even be scaled up to the MW scale in the future. This paves the ground for a large variety of novel application areas of the technology from maritime to small scale stationary and others.

The basic information: https://www.fraunhofer.de/en/press/research-news/2022/march-2022/obtaining-hydrogen-from-methanol.html

PROJECT HIGHLIGHTS

This year's project highlights section is like a walk through the entire project portfolio of Fraunhofer IMM, highlighting strategic elements. True to the approach of building on strengths we are for instance steadily increasing our share of projects dealing with one of the most promising future energy carriers, ammonia. And, of course, our diagnostic/ analytic project portfolio is also well represented.

Use of ammonia as a carbon dioxide-free hydrogen storage medium for the decentralized supply of hydrogen

The implementation of the energy transition poses a major challenge to those sectors of the economy that use fossil fuels in large quantities, for instance mobility. Fossil energy sources must be replaced by regenerative electricity or by regenerative fuels. Power-to-X fuels are synthesized utilizing hydrogen generated by electrolysis, which is produced using surplus electricity either here in Germany or from solar or wind power at more favorable locations abroad. These fuels currently are primarily the hydrogen itself, synthetic methane or other synthetic hydrocarbons. Hydrogen has the major disadvantage that transport to filling stations and carrying it as a fuel in vehicles, either in compressed form as a gas in high-pressure hydrogen tanks or as liquefied hydrogen, involve high costs. The synthesis of synthetic hydrocarbons requires the extraction of carbon dioxide (CO_2) as carbon source from the air at great expense to achieve climate-neutral production.

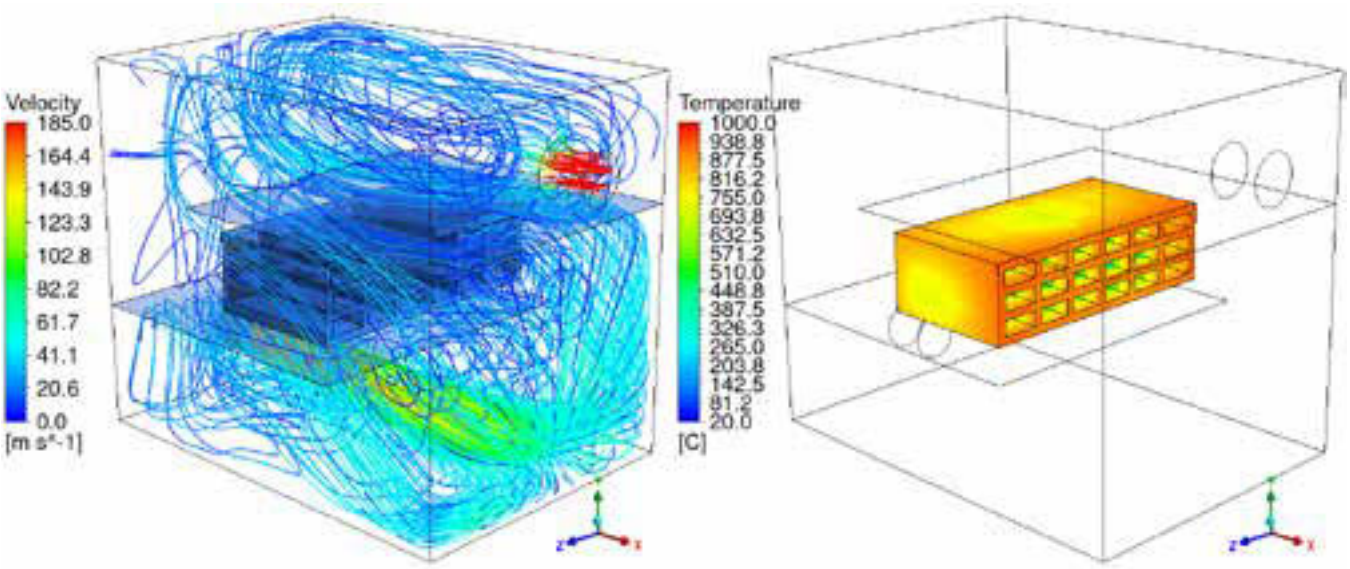
Ammonia (NH_3) is particularly suitable as a storage medium for hydrogen. Since it can already be liquefied at moderate temperatures of -33 °C, its volumetric hydrogen content is significantly higher than that of compressed hydrogen at 700 bar. Compared to hydrogen, liquefied ammonia eases the transport of large quantities to the point of demand. Because hydrogen produced from ammonia does not contain any carbon oxides or methane it is free of greenhouse gases. In addition to its use for hydrogen supply for land vehicles, ammonia can also become economically interesting for maritime propulsion systems, since in this area the CO_2 reduction targets cannot be achieved with conventional fuels, nor does compressed or liquefied hydrogen represent a real alternative for all applications.

For land vehicles, a hydrogen infrastructure must be established at filling stations. To avoid the transport of compressed hydrogen and cryogenic hydrogen, the hydrogen can be produced in decentralized plants, i.e. directly at the filling station through ammonia decomposition.

Fraunhofer IMM Tasks

- development of a stable and highly active innovative catalyst formulation for ammonia splitting
- development of an innovative and compact reactor for the splitting of ammonia, which has the capacity to supply a conventional hydrogen filling station
- verification of the feasibility of the overall concept by converting the produced hydrogen into electricity using a conventional PEM fuel cell in the power range of 50 kW
- use of innovative automation concepts for the operation of the planned demonstration reactor for the decentralized supply of hydrogen based on ammonia
- studying novel routes of photocatalytic ammonia splitting

The AMMONPAKTOR project is funded by the EFRE-REACT program.



Green "Spaltgas" as fuel gas for brick production

Hydrogen plays a key role in the scenarios for achieving the zero-emission energy economy. Thus, intensive research has been conducted in this field since the early 1990s. Hydrogen is one of the most promising energy carriers, because it readily converts to water in presence of oxygen/air. This can be conducted by an electrochemical reaction in a fuel cell and by homogeneous combustion. Hydrogen can be gained from electrolysis of water, which is sufficiently available in most places. The electricity required for the electrolysis can be gained with relatively low carbon footprint from wind and solar energy. The challenges with respect to transport and storage of hydrogen have been presented at the left side of this text in the section dealing with the AMMONPAKTOR project. In consequence, the conversion of hydrogen to ammonia (NH3) is a viable option to provide hydrogen both for industrial processes on a large scale and for distributed utilization of hydrogen. Ammonia can be stored as liquid at 20 °C and a pressure of 8-9 bar similar to LPG. Liquefied at -33 °C it can also be transported in refrigerated transport units.

However, ammonia is not flammable in air and consequently not applicable for energy generation through combustion. Ammonia can be cracked into nitrogen and hydrogen in a cracking reactor over suitable catalysts. A mixture of ammonia, hydrogen and nitrogen is flammable and can be used as a combustible gas, the so-called "Spaltgas". Within the "Spaltgas" project, burner technology will be developed for the mixture which will be used for burning bricks Relying on green ammonia produced from hydrogen generated via electrolysis by the Haber-Bosch process makes the entire process chain of brick production CO_2-free.

Fraunhofer IMM Tasks

- creation of a process engineering model for the design and dimensioning of the burners
- construction of a lab test combustion chamber for burning small numbers of bricks, using IMM test stands to check its functionality and safety, operation of this test combustion chamber
- emission measurements
- development and design of a scalable decomposition reactor as well as a combustion chamber for the pilot plant, upscaling of the entire combustion process to pilot level
- conceptual design and construction of a NOx removal module
- economic assessment of the utilization of green "Spaltgas"

The SPALTGAS project is funded by the German BMBF under the "KlimPro-Industrie" program.

Development of an innovative reactor concept for the utilization of carbon dioxide from biogas plants

Transforming today's energy production towards zero carbon emissions requires among others an efficient utilization of primary resources. Renewable methane (i.e. biogas) allows the reduction of greenhouse gas emissions. The injection of biomethane (methane after biogas upgrading) makes the direct coupling of the electricity grid with the gas grids feasible. This opens up opportunities for the development of highly integrated energy concepts, which can solve the problems of the imbalance between renewable energy supply and demand, seasonal fluctuations could be equalized.

Biogas contains approximately 50% carbon dioxide which has to be separated before injection of the biomethane into the gas grid. Here the Fraunhofer IMM methanation technology comes into play: It allows the direct conversion of the carbon dioxide with (renewable) hydrogen from electrolysis - without prior separation - generating a surplus of biomethane.

The overall objective of the project is the upscaling of the catalytic methanation of carbon dioxide contained in raw biogas. The core element of the process is a two-stage reactor concept, specially designed for the specific conditions of biogas streams and based on a preceding project. Targeted is a mobile methanation plant operated at a biogas plant site to verify the practical feasibility of the developed process. The commercial utilization of the heat generated by the methanation process also allows the coupling with district heating networks.

The second important goal of the project is a profitability analysis of different scenarios of biogas plant operation. In a systemic perspective, the transformation of the biogas plants from current production of electricity to combined production of biomethane and heat is investigated. The development of the envisaged methanation technology can generate a tangible future business model for biogas plant operators suffering from the expiration of current subsidies for electricity production.

Fraunhofer IMM Tasks

- modelling and development of the entire methanation process with all its components, reactor design, reactor fabrication
- provision of the container-based plant environment, assembly of reactors and plant components, installation of gas pre-treatment
- first demo plant test at IMM with special focus on critical components and parameters and system control equipment
- demonstration of continuous integrated operation of the demo plant at partner's site, evaluation of system performance
- conception for a commercial plant and elaboration of technical and economic recommendations

The ICOCAD2 project is funded by the German BMEL under the "Nachwachsende Rohstoffe" program.

Building an administrative and regulatory ecosystem for a scalable, intelligent and digitized open-access rapid testing platform for the detection of pandemic pathogens

Preventive screening and massive, non-induced testing of even asymptomatic individuals by means of PCR-based rapid tests can guarantee normality of life under pandemic conditions and bring social and economic benefits. Once a pandemic starts, such tests need to be available almost instantly, everywhere and in large numbers; they must be able to sensitively detect infections within a few minutes and have to be able to immediately transmit the test results to decision-makers, thus contributing to the effective interruption of infection chains. Antigen tests are currently used alternatively, however, they are less sensitive and a higher number of wrong, negative test results may occur. The adaptation of antigen tests is also significantly delayed compared to PCR-based tests, as the development of sufficiently specific and affine antibodies is much more time-consuming compared to the development of a specific molecular diagnostic test which can be ready immediately after the pathogen sequence data is available.

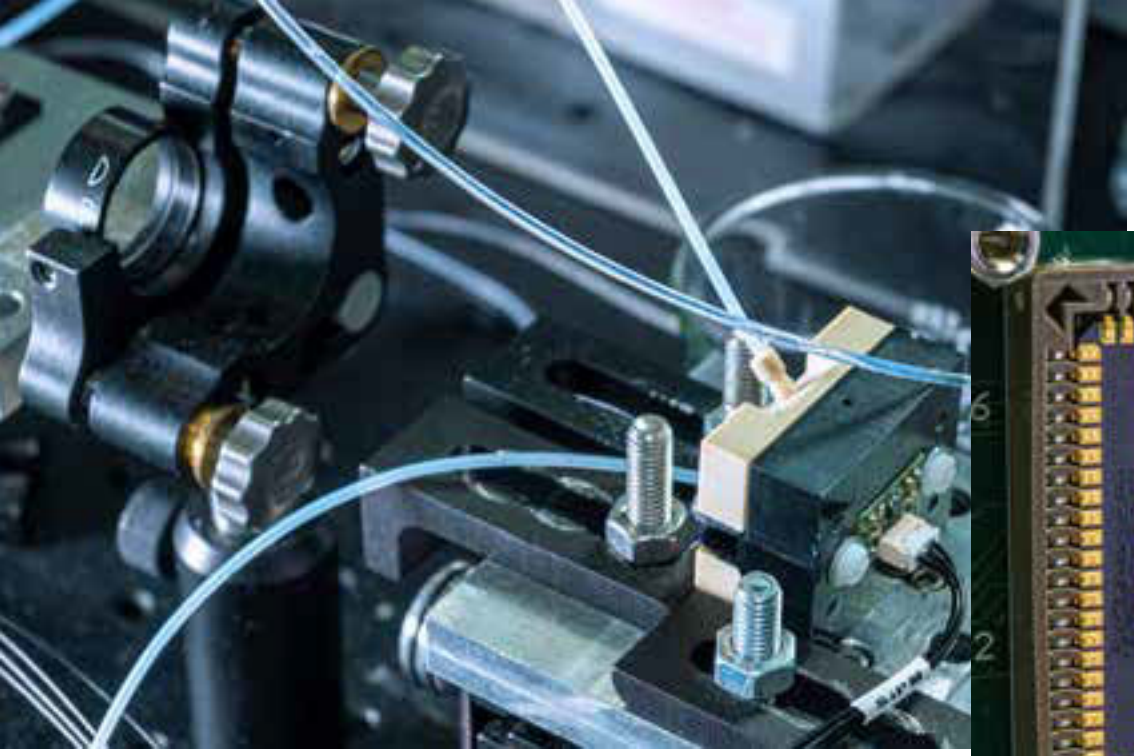
The aim of the "OPEN-POCT" project is to develop a holistic concept, including an administrative and regulatory ecosystem, for nationwide and both financially and organizationally realistic mass testing of the population in a pandemic outbreak. For this purpose, a scalable, intelligent, open, digitized and sensitive POC-PCR rapid test system is suggested, allowing to contain the spread of infectious agents as quickly as possible, to protect lives and to guarantee normality. The focus is on new business models that can access highly scalable production capacities when needed, and to which the broadest possible range of manufacturers and companies will be able to contribute. In addition to the design of a reliable, inexpensive, digital, and rapid POC-PCR rapid testing system and the testing of individual components, further concepts for containment will be developed. This includes communication with authorities, companies, physicians, and other institutions.

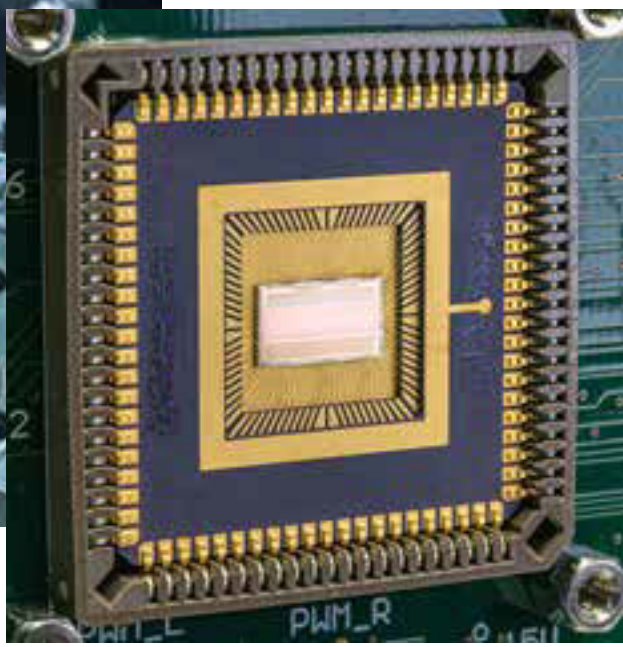
Fraunhofer IMM Tasks

Initiating a re-thinking of test strategies by enabling PoC-technologies for rapid mass testing and discussing ways to expand the interpretive range of the current approval processes by:

- determination and documentation of requirements and use cases
- development of concepts for an improved test strategy using a PoC-PCR platform
- development of approval concepts for single components and the OPEN-POCT platform
- development of a test setup from the reviewed individual components of the platform.

The OPEN-POCT project is funded by the state of Rhineland-Palatinate via the EFRE-REACT program.





Detection of germs in drinking water

Germs can occur anywhere in the drinking water network. Central monitoring in the treatment plants alone is often insufficient to prevent contaminated drinking water from reaching the end user. A comprehensive monitoring of microbial contamination in the drinking water network and in industrial process water requires fully automated, cost-efficient and compact sensor systems with which the microorganisms can be detected quickly and sensitively directly at the point of sampling. For years, IMM has been receiving an increasing number of requests from SMEs for automated sensor solutions that can reliably detect the number of germs in drinking water and are suitable for widespread on-site use, especially directly at the end user site.

One promising detection method is fluorescence-based flow cytometry. To overcome the issues of commercially available systems, which are bulky, comprise expensive optical components and require manual sample processing, a novel flow cytometer is being developed. Under the "IMFLUSS" project, important steps towards its automation and miniaturization have been made:

At the Fraunhofer IMM, a small-size microfluidic channel system made from silicon was built which was shown to eliminate the need for sheath currents. Additionally, the automation of live/dead staining using microfluidic mixing technology together with single-cell fluorescence methods integrated onto a single chip was demonstrated, where the fluorescence intensities almost equal those of laborious manual methods.

Fluorescence lifetime measurements with sub-ns time resolution based on a single-photon avalanche diode array (SPAD array), which was developed by the Fraunhofer IMS, renders optical filters unnecessary and allows for multi-color detection using only a single detector. This enables a further miniaturization of the system such that an inexpensive, fully integrated, miniaturized germ detection method can become a reality.

Fraunhofer IMM Contribution

- development of a miniaturized detection unit for fluorescence lifetime detection without requiring optical emission filters
- implementation of automated fluorescence staining by using micromixers
- set-up and validation of a demonstrator for the cost-effective, automated on-site determination of the total bacterial count in drinking water

Point-of-use detection of microbiological hazards in environment and industry

Waterborne diseases cause 2.2 million deaths worldwide and a significant economic loss of nearly $ 12 billion per year. A commonly known example is "Legionnaires' disease" which is caused by bacteria called Legionella. Biological hazards like this can be prevented by identifying target microorganisms and timely decontamination actions. A real-time response to health hazards and biological threats that spoil industrial products or infrastructures are eagerly demanded. However, culture-based methods, as the gold standard, for bacterial detection and identification are too time consuming and they cannot detect viable but non-culturable bacteria, making them unsuitable for rapid and accurate detection. Desired solutions must provide high specificity to detect microorganisms in due time (typically < 1 hour), and at the same time, must be cost-effective, possible to be implemented on-site and fully automated. Molecular detection methods like PCR are ideal candidates but the penetration of industrial markets is so far hindered by the tedious sample preparation process to extract microorganisms.

Fraunhofer IMM is developing a miniaturized point-of-use device called "InBaDtec" aimed at fully automated preparation of water samples prior to the use of qPCR analysis. With this device, the on-site detection of pathogens from large water sample volumes (one liter or more) will become possible. Among the various techniques for concentrating bacteria from large volumes, microfiltration is comparatively simple and fast. The concentration process is carried out in two steps using an integrated microfluidic technology, first concentrating the bacteria in the 1-l sample in 10 ml and then finally in 200 µl of liquid. The "InBaDtec" system itself is completely cleanable and reusable. The only consumables are insertable plastic filter membranes. The technology developed can be also applied for the biosafety control in a wide range of industries including pharmaceuticals, food and beverage, algae and fish farming, bioreactors and bioprocessing, cosmetics, defense and biosecurity, chemicals such as painting and coating, glue, cooling lubricants as well as fuels such as kerosene and diesel.

Fraunhofer IMM Progress

- currently the experimental validation of the concentration process is performed
- water samples containing bacteria can be concentrated from a volume of one liter to 200 µl automatically in less than ten minutes
- results with E. coli pathogens in water samples show that an increase of the detection limit of qPCR by a factor of 1,000 is possible compared to a procedure without concentration

The InBaDtec project is funded by Fraunhofer internal programs.

Detection of only viable microorganisms in environmental and industrial media using a non-toxic and specific pre-treatment in conjugation with qPCR

Microbial contamination in water and food can threaten human health or cause economic losses as the consequence of product deterioration and destruction. Fast and easy-to-use methods for robust and sensitive detection are urgently required to improve this status quo. Current methods to monitor the microbial load rely on culture techniques or molecular detection by polymerase chain reaction (PCR). A traditional culture is time-consuming and lacks sensitivity; moreover, it also results in underestimating the contamination caused by a so-called viable but non-cultivable (VBNC) state of the bacteria. PCR, as a molecular detection method, is fast and sensitive, but also leads to a fatal overestimate, due to the disability to differentiate between the relevant living and dead microorganisms. One approach could be the use of dyes penetrating dead cells selectively and blocking subsequent PCR amplification. In fact, the toxic concentration of the dyes is easily exceeded being prohibitive for a reliable routine method.

The LivEnz project proposes a novel solution to combine routine PCR technique and a non-toxic and specific pretreatment to detect only the viable microorganisms. This pre-treatment is able to ensure that there are no false positive results by selectively inhibiting the DNA amplification and detection from dead cells only, while also ensuring that there are no false negative results from live cells due to its non-toxicity, thus to precisely estimate the pathogen risk. Moreover, the elimination is specific to microorganism strains, so it can allow, for example, for a certain pathogen strain to distinguish between alive and dead, whereas not for another strain, if there is such a special need. Compared to bacterial cultivation, which can take several days, this method will be less time-intensive delivering results within minutes to a couple of hours while allowing the detection of VBNC microorganisms and live/dead discrimination. The LivEnz method will as well offer the opportunity to be implemented in a miniaturized, automatized analysis system to facilitate sample analysis at the point of need.

Fraunhofer IMM Tasks

- investigating the general feasibility of the method by using purified DNA from E. coli
- development and optimization of the protocol for bacteria sample pre-treatment
- proof of concept for the application of the method to discriminate between viable and non-viable microorganisms by PCR
- expand this method to other and multiple microorganism strains

The LivEnz project is funded by Fraunhofer internal programs.

Long-term stable process for the production of nanoparticles

Many modern active pharmaceutical ingredients exhibit poor water solubility and highly lipophilic properties, negatively affecting the administration to the patient. The delivery form can be improved if the size of the drug particles is reduced resulting in the formation of fundamentally different biophysical properties compared to macro particle systems. Appropriate nanoparticles of drugs or colloidal carrier systems for such drugs are able to provide significant advantages for the bioavailability. However, the production of these particles in sufficiently high pharmaceutical quality remains a challenge, which is especially valid for parenteral forms of administration. Quality characteristics of a pharmaceutically applicable process are high reproducibility, a narrow particle size distribution and small average particle sizes. The inline-monitoring of these parameters in small quantities is vital in the development of pharmaceutical products.

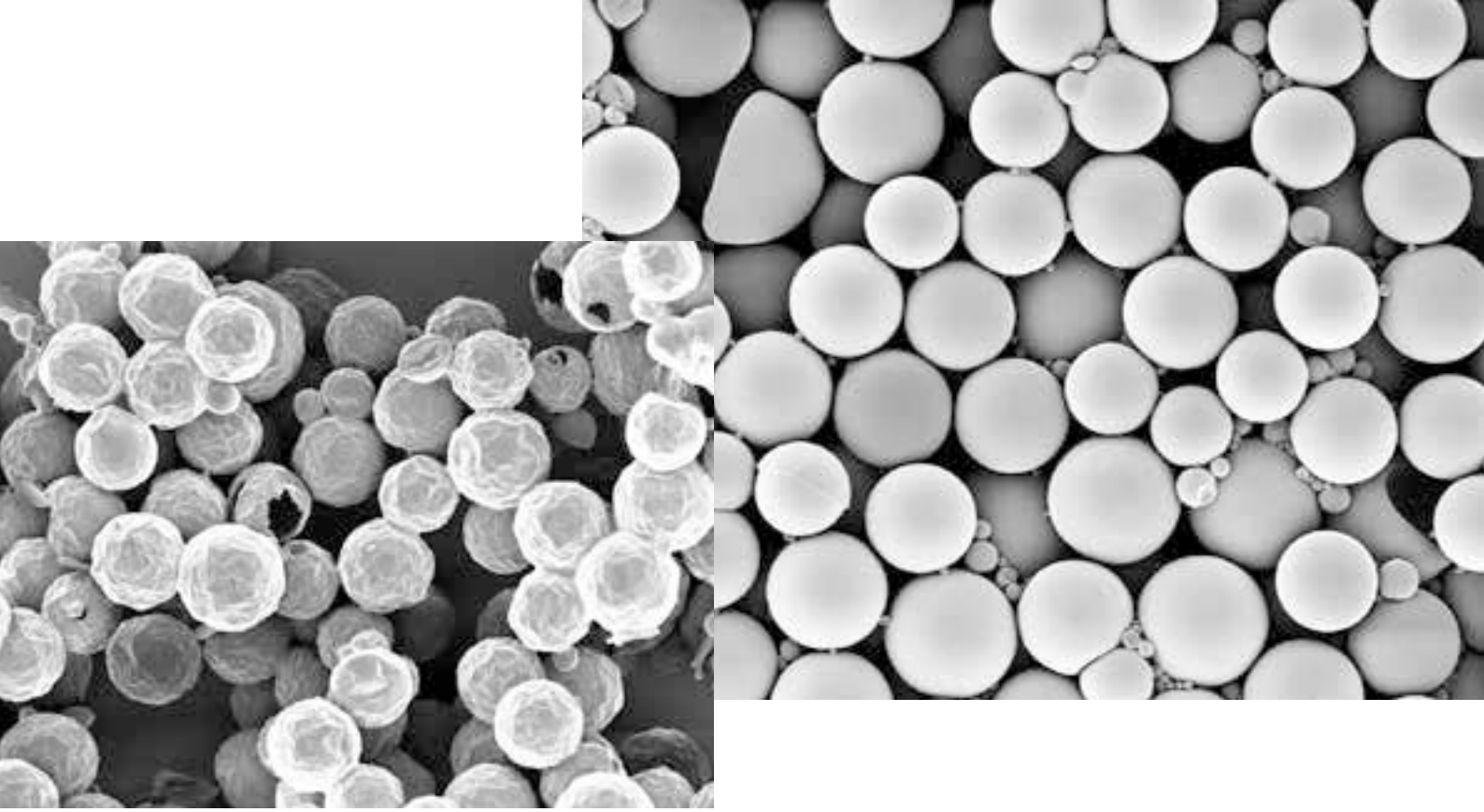
Within the DETECTED project, the nanoparticles are produced by precipitation from molecular drug solutions in microfluidic chips to controllably produce particle sizes of around 100 nm and narrow size distributions (IMT, Braunschweig). The integration of our patented flowDLS technology (dynamic light scattering of flowing particles) allows for an inline-monitoring of their size characteristics. The goal of the project is the realization of a nanoparticle reactor with which the size, size distribution and shape of the manufactured particles can be precisely measured and adjusted.

To achieve this, we have adjusted the optics, fluidics and firmware of the flowDLS to accurately measure particles in cuvettes as small as 500 µm at flow rates of up to 500 µl/min. We have demonstrated the integration of the flowDLS optics directly onto the same microchip used for synthesizing the particles. By adjusting the process parameters, their influence on particle size can be readily determined via our flowDLS. In this manner, a deep process understanding can be gained very quickly, enabling not only the acceleration of drug development, but also allowing for a feedback regulation of the particle production, thus ensuring a long-term stable process.

Fraunhofer IMM Tasks / Results

- adaptation of the DLS system to the use of flow-through cuvettes on the smallest scale; development of a microfluidic system which can serve as such a flow cell
- development of a modular exchange system for the flow cell
- adaptation of hardware and software in the flowDLS system
- combination of a microprecipitation system with the microfluidic flow-through cuvette, resulting in a monolithic microfluidic system

The DETECTED project is funded by the Deutsche Forschungsgemeinschaft DFG as trilateral transfer project.



Metrology for the determination of emissions of dangerous substances from building materials into indoor air

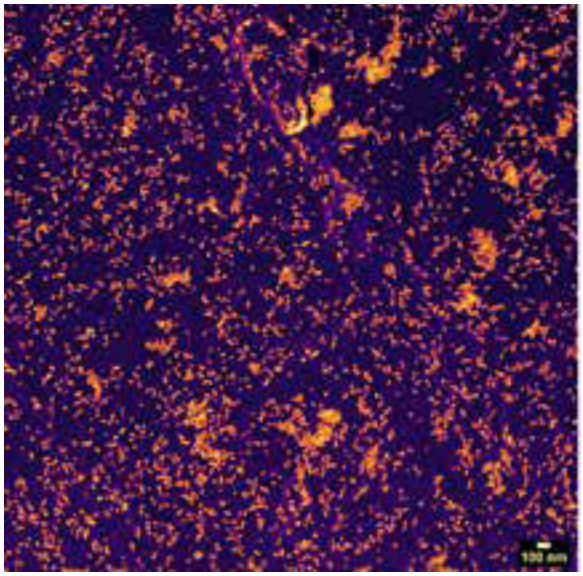
As European citizens spend more than 80 % of their time indoors it is vital that the release of harmful substances from building materials (for instance paints, flooring, furniture …) into the air is minimized or even avoided. For consumer protection at national and European level a bunch of standards, evaluation concepts and labelling schemes does already exist but they are so far only mandatory in a few EU member states. Once being legally required in the whole EU, all member states will have to set up an appropriate testing infrastructure. In the end, a high level of consumer protection can only be achieved when accurate and comparable measurements are possible. Recent time studies in this field have either focused on a very limited number of reference materials, did not entirely consider long-term stability or showed remarkable deviations of reproducibility up to a few hundred percent.

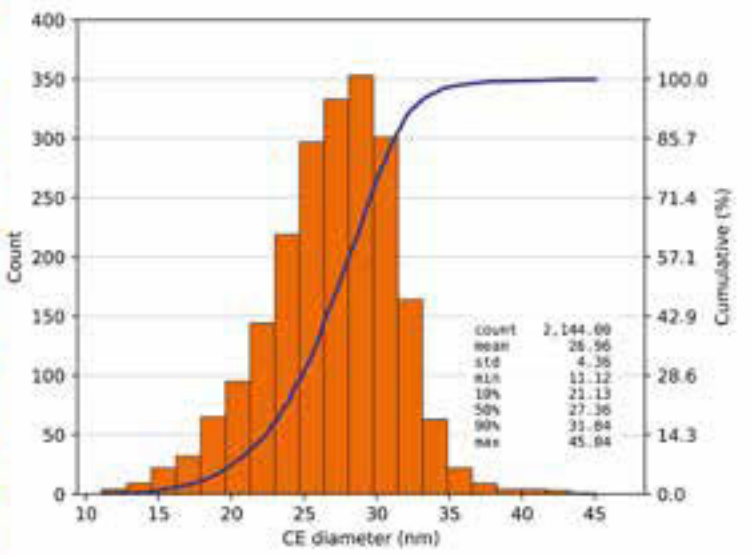
The overall goal of the MetrIAQ project is to provide an emission reference material (ERM) with a constant emission profile and gaseous certified reference materials (gCRM) of indoor air pollutants that are relevant for the health-related evaluation of building products such as aldehydes, unsaturated aldehydes, cyclic dimethylsiloxanes and glycol compounds. This will be supported by numerical modelling work simulating transport processes in the ERM allowing to predict emissions of target compounds. A validation part will investigate the short- and long-term stability, reproducibility and lab dependencies providing evidence of the benefits of the new reference materials, consequently contributing to standards development work.

Fraunhofer IMM Tasks

- supporting the development of an ERM prototype: Development and synthesis of different polymeric microcapsules loaded with a single volatile organic compound by polycondensation/polyaddition interfacial reaction in direct (oil-in-water) emulsion
- supporting the characterization or the ERM prototype with respect to size, polydispersity, morphology, chemical composition, encapsulation efficiency and stability

The MetrIAQ project is funded by the European Commission under the EMPIR (European Metrology Programme for Innovation and Research) program.





In cooperation with the Norwegian Institute for Water Research (NIVA)

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Nanosilver 109

In nanoparticle synthesis, the primary goal is generally to achieve a narrow particle size distribution. Classic material systems described in literature are colloidal gold and silver particles, which can be obtained by wet-chemical synthesis. Both gold and silver nanoparticles are optically active, their strong plasmon resonance (collective oscillation of the conducting electrons against the atoms inside the particle) yield to a strong distinctive absorption band in the visible spectrum. Depending on the concentration, a strong ruby red for colloidal gold and yellow to brown color for colloidal silver is resulting. Gold nanoparticles are used for instance in antigen test kits for Corona virus or pregnancy hormone. Silver particles possess antimicrobial activity serving as a reservoir for the release of silver ions and making them attractive for a number of products with anti-microbial surface coatings. In this context, product safety, the fate of the material during and after its lifetime, is an important aspect, with respect to the consumer and the environment. Besides chemical safety, the "nanosafety" of engineered materials becomes increasingly important for the registration of chemicals and product safety in general.

Naturally occurring silver is composed of a mixture of the species ^{107}Ag and ^{109}Ag to almost equal parts. The Norwegian Institute for Water Research (NIVA) requested to prepare nanoparticles purely made of ^{109}Ag for studying their environmental fate, thus, allowing to trace the particles in complex matrices such as wastewater and to discriminate other potential silver content in the analyte coming from other sources, which would contain the natural isotope mixture. Inductively coupled plasma mass spectroscopy (ICP/MS) is a very sensitive method in analytical chemistry allowing to discern even specific isotopes of a given element, i.e. atom cores that contain a few neutrons more or less and therefore a slightly different mass, while they behave chemically identically.

Fraunhofer IMM Work

- demonstrating the feasibility: A synthesis protocol was developed with natural silver yielding the desired particles size, concentration and total amount required. A small-scale experiment confirmed the viability of the protocol for isotopically pure ^{109}Ag
- samples analysis: Transmission electron microscopy (TEM), dynamic light scattering (DLS) and analytical centrifugation was performed at IMM confirming the specifications. At NIVA, the silver concentration of the final colloidal solution was determined by ICP/MS, confirming quantitative reaction yield
- synthesis scale-up: The final synthesis was well reproducible with the rather costly ^{109}Ag and yields particles perfectly within the desired specifications, as proved with the same characterization methods mentioned before. Compared to previous work from literature, a 50 x scale-up was achieved (10 x concentration, 5 x volume), resulting in particles with a substantially more narrow size distribution

Recyclable and biodegradable packaging materials by wet-chemical coating of paper with biopolymer dispersions

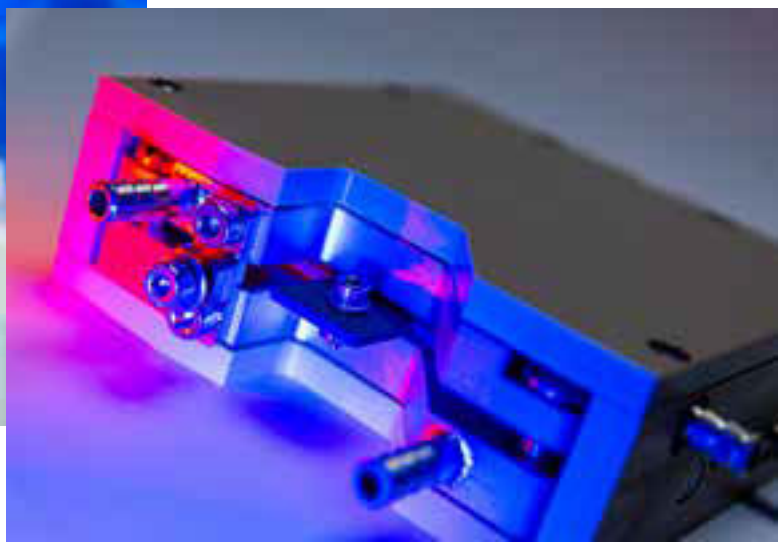
With its "Bioeconomy Policy Strategy", the German federal government has initiated an economic paradigm shift towards innovative forms of sustainable, bio-based economic activities. One goal is to achieve a significant and sustained increase in the share of biomass and the efficiency of its use by the support of innovative technologies and products. Additionally, driven by the raw material situation, market trends and the issue of sustainability, the interest in renewable raw materials in the paints and coatings industry has been increasing noticeably within the past decade. In particular, the opportunities of bio-based coatings, especially those with new or improved functionalities, are considered great by experts from industry and science.

The overall objective of the BioPack project is to develop a novel, bio-based packaging material using the renewable raw material paper, cardboard or paperboard as a carrier material. Dispersions from bio-based and biodegradable (compostable, ideally) polymer particles will be used to produce coatings with optimized properties in terms of application behavior, barrier integrity and storage stability. Thus, compared to conventional paper packaging, new and enhanced barrier properties can be achieved allowing the packaging to compete with petrochemical alternatives. For the application of the coating, a wet-chemical approach is chosen and the application technique is optimized with respect to the requirements of a closed film formation while realizing low film thicknesses. This allows for a lower coating thickness compared to extrusion coating. Besides an increase in resource efficiency, a lower layer thickness also leads to a lower amount of additive material in the recycling of the cellulose fibers which, in turn, substantially improves the recyclability of the packaging material. Due to these improvements, but also due to the biological origin of both the coating as well as the carrier material, a considerably better environmental balance is achieved. The bottom line is that the highly innovative packaging material will combine ecological and economic advantages.

Fraunhofer IMM Tasks

- development of a production process for the raw dispersion while optimizing particle properties by application of systematically varied formulation parameters
- characterization of the particles with respect to their size, size distribution and agglomeration state by using established analytical methods such as dynamic light scattering, transmission electron microscopy, and analytical centrifugation

The BIOPACK project is funded by the German BMEL under the "Nachwachsende Rohstoffe" program.



Anti-virus-aerosol: testing, operation, reduction

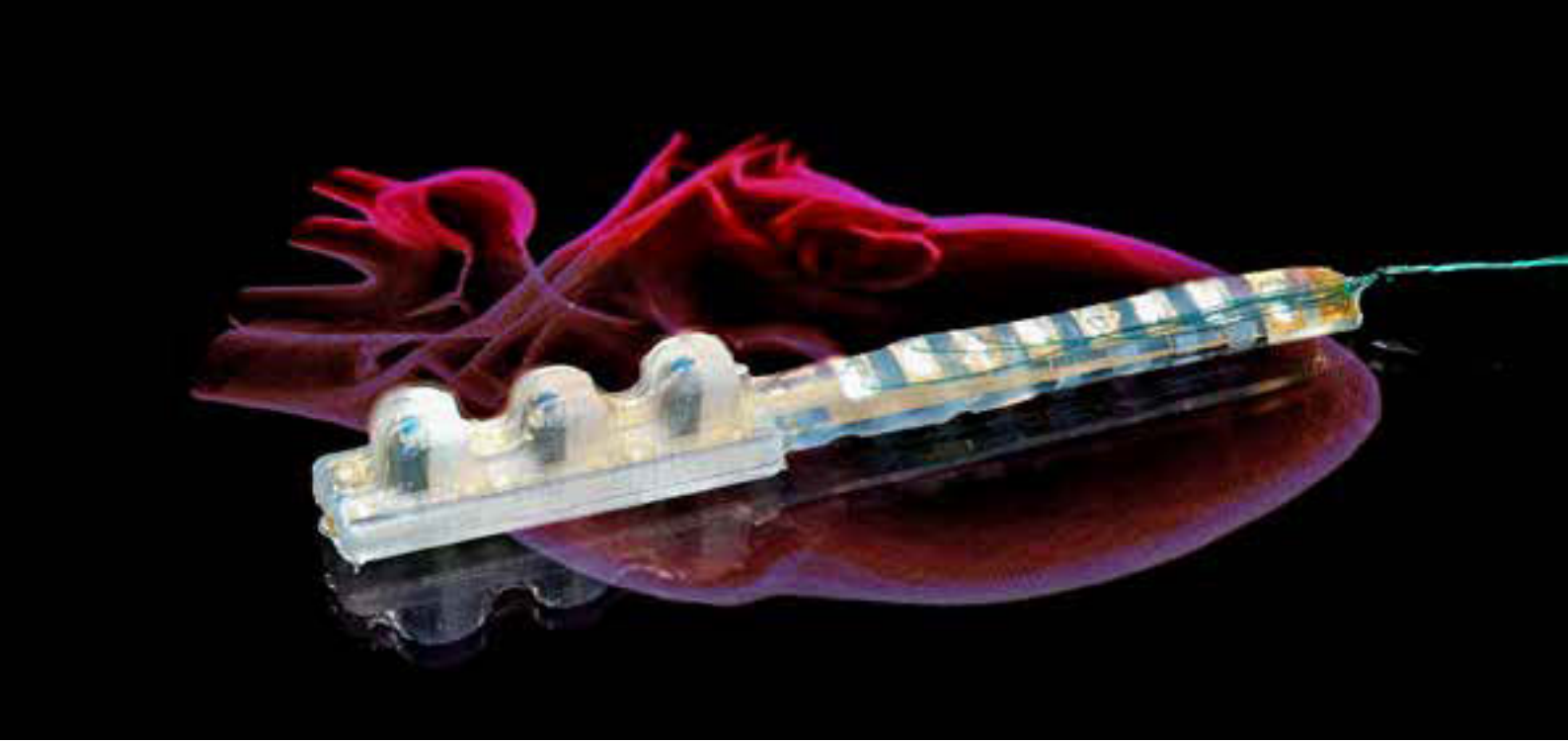
While the spread of many pathogens occurs mainly via the so-called smear infection, the SARS-CoV-2 pandemic has shown that exhaled aerosols with particles smaller than 10 µm play an important role in the infection process. Aerosols remain airborne for a long time. Thus, the risk of infection in crowds of people in poorly ventilated indoor areas increases significantly. Especially hospitals, care facilities, accommodation and hotel businesses, operators of airplanes, trains and production plants, for instance in the food sector, need advice on hygienic issues as well as practical solutions to prevent the spread of aerosol infections. Breaking the chains of transmission and thereby slowing the spread is a major goal in pandemic situations.

With the AVATOR project, anti-corona research was bundled in form of a joint research project with 16 participating Fraunhofer institutions, coordinated by Fraunhofer IBP. The activities included simulation of aerosols in buildings and airplane cabins, different approaches for air filters, i.e. virus reduction, and validation. Within the project consortium, a more detailed understanding about the involved processes was obtained in regard to the prediction of the spread of virus-laden aerosols and to purification technologies of indoor air, which together may lead to new concepts for reducing infection with such pathogens. Hygiene concepts for different application scenarios were derived. In parallel to the simulation-based assessment of aerosol spreading, air purification technologies based on both virus capture and inactivation have been developed. Efficacy of inactivation has been proven via a virus-laden test aerosol being developed and applied in test environments. The experimental validation was scheduled in real test environments as the Indoor Air Test Center, a school building and a flight cabin lab located at Fraunhofer IBP.

Fraunhofer IMM Tasks / Results

- development of an electrochemical reactor and mobile plant for the on-site electrochemical synthesis of peroxydicarbonate as potential virucide from sodium carbonate
  - efficient production of peroxodicarbonate, intended to work as harmless and cost-effective virucide, as it self-decomposes into non-hazardous products
  - other application areas such as waste water treatment and industrial bleaching processes can be addressed
- development of an air surveillance system for the optical detection of virus particles
  - proof-of-concept for the aerosol collector and optical detection system
  - employment of liposomes as test material with virus-like physicochemical properties, which may be developed further for the characterization of air filters

The AVATOR project is funded by Fraunhofer Internal Programs.



Improving the quality of life after heart transplantation

Transplantation of a donor heart is often the last possible option to save the life of individuals suffering from severe end-stage heart failure. Worldwide, about 3500 heart transplantation surgeries are carried out every year. Although this intervention may significantly increase life expectancy of heart failure patients, the health-related quality of life of the transplant recipients is in most cases considerably limited. This is due to the inevitable denervation of the transplanted donor heart which in particular prevents the parasympathetic control of the heart rate dependent cardiac activity by the vagus nerve. In consequence, recipients are affected by a seriously increased resting pulse rate and the incapability to modulate the heart rate under physical exercise.

This fundamental problem of today's heart transplantations is specifically addressed in frame of an European research project, that is focused on the development of a novel bio-electronic solution enabling restoration of the vagal control of heart activity in heart transplant patients. The resulting neuroprosthetic system uses a dedicated multi-channel neurostimulator implant for demand-controlled closed-loop neuromodulation of the vagus nerve via a regenerative neural electrode interface. The latter is placed in between the transected ends of the vagus nerve cord of the patient and on the donor heart. Closed-loop control of the neuromodulation is achieved with a dedicated sensor implanted in the myocard which monitors the heart activity and provides the feedback to the stimulator device.

Successful completion of this development might be a ground-breaking milestone on the road to reducing currently existing limitations and epiphenomena associated with heart transplantations. This would not only improve the quality of live and live expectancy of the affected but also reduce duration and cost for post-surgical rehabilitation and the number of clinical revisions as well.

Fraunhofer IMM Tasks

- design, layout and realization of a MEMS-based sensor implant for monitoring the heart activity via the contraction of the myocard
- lab-bench concept validation and optimization by means of soft tissue dummies made from silicone and gelatin simulating the properties of myocardial tissue
- provision of a first generation of sensor implants for acute in-vivo performance testing and validation on a pig model
- design and manufacturing of an optimized sensor implant with integrated AD-conversion for in-vivo validation of the complete neuromodulation system developed under the project

The NeuHeart project is funded by the European Commission in the frame of the Horizon 2020 FET Proactive subprogram.

On-site detection of bacterial toxin contaminations in food

Microbial contaminations in food represent a major health risk, as they can lead to severe infections and intoxications. In addition, reputational and economic damage of food companies concerned may be a consequence due to obligatory recalls and rejections of entire product charges. Therefore, the assessment of microbial burden of food samples is an important measure, for example to check for Staphylococcal enterotoxins. However, currently available methods require resource- and time-intensive laboratory analysis. This results in a critical delay in the detection of contaminations and further action that is needed to contain and prevent potential outbreaks.

With "PhoTox", Fraunhofer IMM has started to work on the development of an innovative analytical system for on-site detection of bacterial toxins in food. The central preconditions to realize this are an automated and fast analysis, a signal detection that does not require a complex optical setup, and a photosensor that allows a highly sensitive detection. To reach this goal, six project partners from university, Fraunhofer and industry concentrate their competences from the fields of analytical disposables, instrument engineering, dairy research, microfluidics, microelectronics and sensors under the coordination of BYTEC Medizintechnik GmbH.

Fraunhofer IMM Tasks / Results

- development of a microfluidic food sample preparation strategy
  - establishment of a method to prepare dairy samples that is reduced to a minimum and suitable for application on-site; testing
  - design and manufacture of components; process transfer
- development of an analysis cartridge
  - conception of a microstructured cartridge; prototyping
  - fluidic testing and assay transfer

In combination with a novel chemiluminescence-based immunoassay (CLIA), a single photon avalanche diode (SPAD) sensor and device as well as disposable solutions compatible for mass production, this will allow a future on-site testing without any laboratory infrastructure.

The PhoTox project is funded by the Federal Ministry of Education and Research Germany.

Towards industrial implementation of an intensified chemical process

The chemical industry is on one hand a wealth-creation sector within the European economy but on the other hand linked with considerable environmental impact. Concern about climate change and other environmental issues demands from the chemical industry to shift to greener, safer and sustainable production processes. The EU funded INCITE project, the acronym standing for "Innovative Chemoenzymatic Integrated Processes", picks up this challenge by following novel integrated upstream and downstream processing paths involving flow chemistry and membrane technology in chemoenzymatic processes and demonstrating their potential in industrial setting for two process chains. One leading to an oleochemical commodity, the other one to a fine chiral chemical being used as agrochemical in the field of crop protection and public health. Fraunhofer IMM focus is on the latter process covering the two-step chemical process preceding the enzymatic conversion.

Core of the considered process chain is the synthesis of a reactive intermediate bearing process safety challenges. These challenges are addressed by applying apparatuses and methods of chemical microprocess technology including flow reactors and membrane separators. So, Fraunhofer developed starting from batch recipes a continuous process at lab scale linked to a reduction of process time from several hours to a few minutes and managed the direct coupling of the two steps, i.e. direct usage of the reactive intermediate. In sum this led to a reduction of reactive intermediate inventory in the process by a factor of 100 – 200 which represents a fundamental gain for process safety.

The activities within INCITE now focus on contributing to the implementation of the process within an industrial setting of one of the project partners. For this, in view of Fraunhofer IMM reactor technology a scale-up factor in the range of 100 is required while keeping the key characteristics of lab installation and lab process. Corresponding flow reactors have been successfully developed and realized and are now in the phase of implementation in corresponding process modules for later shipment to the industrial partner. Albeit the reactors only have reactor volumes in the range of hundreds of cm^3 they enable demonstration throughput in the range of several tens of tons per year.

INCITE, funding reference: H2020-NMBP-ST-IND-2018-2020/ H2020-NMBP-SPIRE-2019, grant agreement number 870023

RT-PCR-based SARS-CoV-2 detection at the point-of-need – instant, rapid, sensitive, cost-efficient

From December 2019 to this day, the SARS-CoV-2 pandemic has caused more than 120.000 deaths in Germany and 6.36 million worldwide. Although vaccinations have become available, a decreasing immunity that can be observed only few months after application, and constantly developing variants of the virus with altered transmission characteristics have been leading to new waves of infections. To control, contain and manage such present as well as future situations, we need technologies for infection detection that are fast, sensitive, instantly available in a sufficient number, cost-efficient and independent from laboratory equipment or personnel.

Fraunhofer IMMs Vision

Since the beginning of the pandemic, Fraunhofer IMM has consistently been believing in and working on RT-PCR-based rapid tests to address this problem. The key reason for this is, that such tests can combine the advantages of antigen-based rapid tests which are 1. a highly flexible use, 2. immediate test results and 3. low-cost mass testing capacities, with those of molecular laboratory diagnostics, which are 4. maximum sensitivity and 5. the potential to be easily adapted to emerging variants or pathogens. Therefore, in a series of internal as well as public funded single and joint projects Fraunhofer IMM is pursuing its vision of PCR-based SARS-CoV-2 detection at the point-of-need. This stepwise involves the development of a rapid, low-complex and automated nucleic acid amplification-based analyzing system including both reverse transcription and PCR (polymerase chain reaction), the establishment of a simplified method for swab sample preparation and the discussion and consideration of use cases and regulatory conditions.

Remarkable results that have been generated in these projects are

- the development of an automated RT-PCR analyzing system and the general feasibility to detect SARS-CoV-2 RNA
- the establishment of a sample preparation method that is reduced to a minimum and suitable for on-site application outside laboratory environment
- clinical data on the sensitivity and specifity of the technology
- information, concepts and collaboration networks for product development projects

Fraunhofer IMM will intensively focus on the further development of the RT-PCR-based analyzing system and future projects.

WHAT'S NEXT

At a first glance, the section "WHAT'S NEXT" may sound a bit like all being still up in the air. But in fact all of these projects started recently, will start soon or are in concept phase, so that valid conditions to make a difference in these areas are already in place. In other words, the door is open, we just have to walk through it. All efforts are designed to make a sustainable contribution to improving efficient energy supply, food supply and health in the long term, and they thus pay direct attention to the topics mentioned at the beginning of the annual report.

Project SEEDPLUS – Improved crop yield through protective and supportive multifunctional coatings of seeds

Plants form the basis of all life on earth, thus, being indispensable for stabilizing the world's climate and the sustainable supply of food as well as raw materials. Their demand-oriented cultivation as high-yielding crops are among the hugest challenges for present and future generations. SeedPlus will develop innovative complex seed coatings that have inherent water and crop protection management and thus enable effective field emergence even under difficult environmental conditions. This will be achieved by coating the seed with a functional layer for improved water storage (support function) and a selective barrier to protect the seed from the herbicides used (protective function). In this project, the Fraunhofer IMM is developing completely new degradable functional coatings based on biopolymer formulations, which can also be equipped with active ingredients from plant extracts using nanoencapsulation technology, thus promoting plant growth and development.

Activities funded by Fraunhofer internal program

Concept KUEHLZELLE

The aim of the KUEHLZELLE concept is to provide evidence of the feasibility of a future-oriented overall process for the efficient cooling of food using a cooling system powered by fuel cell technology with an output of approx. 10 kW on the basis of renewable methanol. The core elements of the mobile refrigeration supply unit to be developed are a fuel cell reformer system operated with the renewable hydrogen carrier methanol based on a low-temperature PEM fuel cell (LTPEMFC) and a hybrid refrigeration machine that supplies the required refrigeration both from the fuel cell system electricity as well as from their waste heat. The sustainable concept aims to achieve a better utilization of energy by a factor of almost two with drastically reduced emissions and noise pollution compared to conventional approaches.

Project NEXTGENMEDINKUBATOR

An increasing number of process steps will require successful miniaturization in order to guarantee integration capability in more complex process sequences. Additionally, previous work on automation in pharmaceutical production has shown that the acquisition of cell-based parameters such as cell count or cell viability requires a lot of personnel and space, being limiting factors, especially when transferring processes to a mobile and container-based concept. Thus, the NextGenMedInkubator project is dealing with two use cases: a process module for the nanoformulation of relevant (bio)therapeutics based on proven micromixing technology and the realization of a miniaturized flow cytometer that can automatically withdraw and analyze a cell sample from a bioprocess.

Activities funded by the EFRE-REACT program

Project RNAUTO

mRNA-based vaccines, along with gene and cell therapeutics, represent innovative drugs that can be used to prevent and/or treat infectious diseases, genetic disorders and cancer. The primary objective of the RNAuto lighthouse project is to develop automated manufacturing processes for innovative mRNA molecules that will smooth the way for sustainable and cost-efficient healthcare. In particular in the field of special bioanalytics and nanoanalytics as well as in scalable process technology for the formulation of lipid nanoparticles, Fraunhofer IMM will contribute to the success of the lead project with its competencies and expertise in the design, construction and automation of microtechnical modules and systems.

s.fhg.de/en-RNAuto
Activities funded by Fraunhofer internal program

BUSINESS FIELDS

Fraunhofer IMM´s work is driven across the house by existing societal challenges and by sustainable development goals. In order to provide an adequate framework allowing to achieve the goals it is organized in three business fields, having a major focus on sustainable and efficient energy supply, green and sustainable chemistry as well as rapid and personalized diagnostics. Although the topics we are working on are of great importance, the »micro« in our name has always been justified as in many cases highly elaborate tiny structures are making the difference.

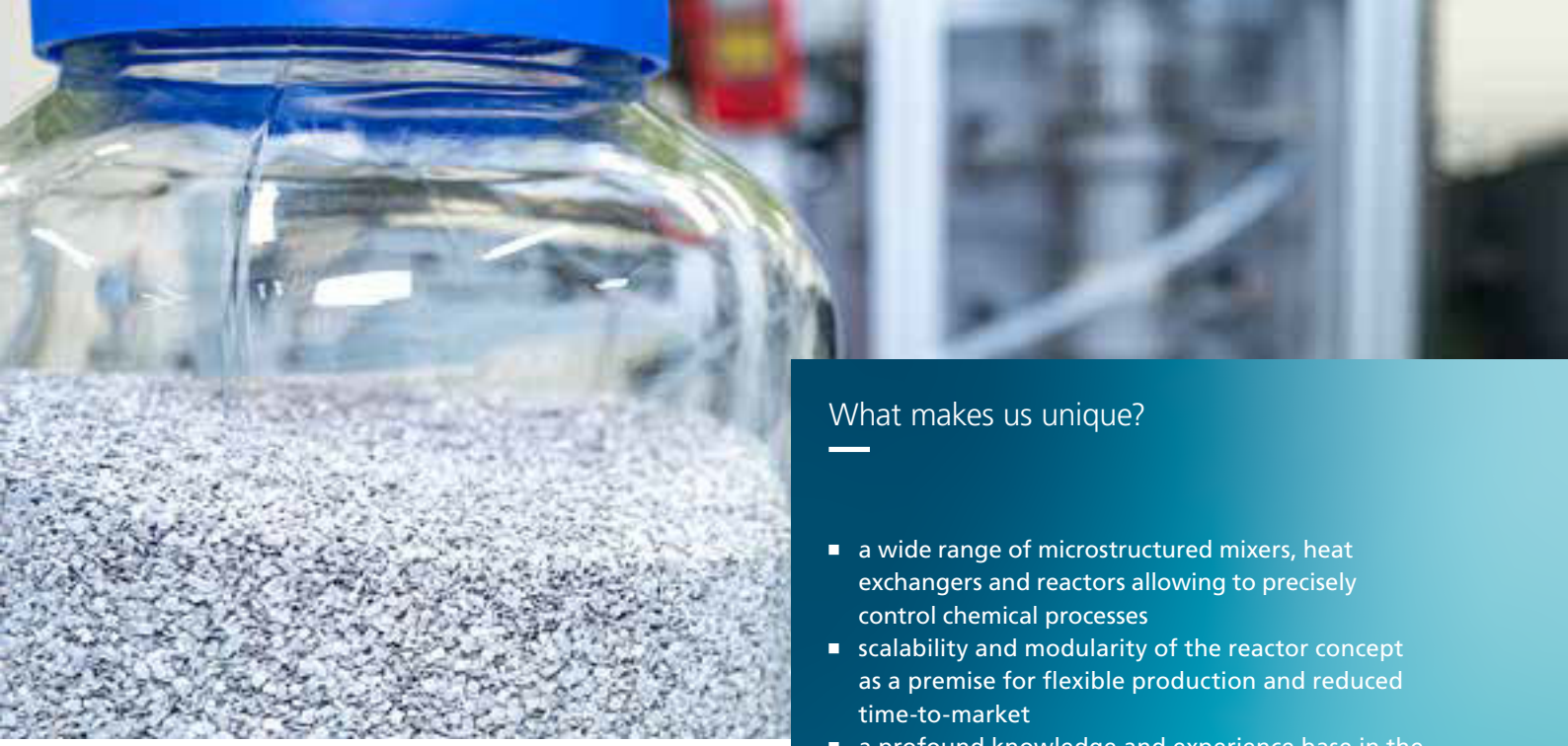
What makes us unique?

- the availability of a mature scalable reactor concept based on microstructured plate heat exchangers that can easily be coated with catalysts
- a portfolio of highly active and long-term stable, robust catalysts for the special application area of fuel processing technology for fuel cells
- a reliable manufacturing technology for the cost-effective production of large numbers of reactors
- all R&D services up to the complete system including the fuel cell from a single source

Energy

Transforming the global energy sector from fossil-based to zero-carbon by the second half of this century will be essential to limit climate change. Due to the fluctuating availability of renewable sources, energy storage will become even more important in near future. The capacity of chemical energy storage is orders of magnitude higher than that of batteries. Hydrogen is such a storage medium while hydrogen carriers such as methanol and ethanol, synthetic hydrocarbons such as methane (natural gas), higher molecular weight liquid hydrocarbon mixtures as a substitute for kerosene or diesel and, currently widely discussed, ammonia have significant advantages concerning power density and storage conditions. Nonetheless the extraction of hydrogen from different hydrogen carriers through catalytic conversion, called fuel processing technology, will foreseeably become one of the central processes of future energy technology.

Since the beginning of the millennium, Fraunhofer IMM has evolved to be the most powerful non-university research unit worldwide working in the field of fuel processing. Projects based on industrial contract research or public funding are arranged along the entire technology chain: system design, process simulation, catalyst development, durability tests, reactor design, development of cost-effective manufacturing technologies, system control, system integration and system testing. Dynamic hydrogen supply for fuel cells, including the reforming of natural gas, LPG, methanol, ethanol, propylene glycol, gasoline, kerosene, diesel for stationary as well as mobile applications in the field of aircraft assistance, maritime applications and agricultural vehicles, transport and automotive is a major part of the portfolio. Combined heat and power units for small to medium stationary solutions, ammonia utilization for powering off-shore vessels and reducing carbon dioxide in industrial processes, the utilization of green hydrogen in power-to-gas applications and the purification of reformate or exhaust gases are further outstanding project examples. The construction, realization and testing of highly compact microstructured reactors for fuel processing, ammonia decomposition and catalytic methanation, the associated catalyst technology, the construction of complete fuel processor systems and their coupling with fuel cells and finally the automation of systems with and without fuel cells complete the expertise.



What makes us unique?

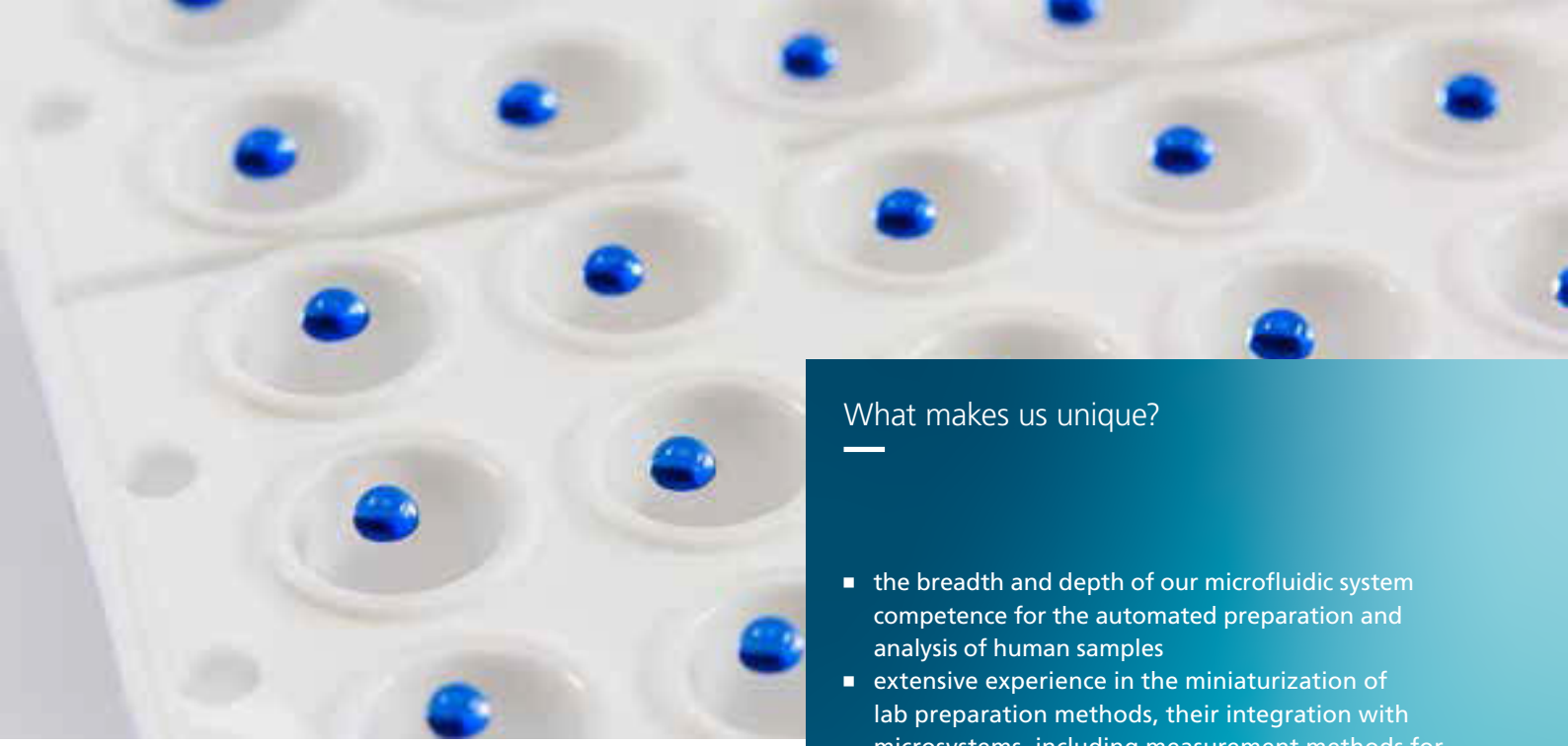
- a wide range of microstructured mixers, heat exchangers and reactors allowing to precisely control chemical processes
- scalability and modularity of the reactor concept as a premise for flexible production and reduced time-to-market
- a profound knowledge and experience base in the transfer of batch to continuous processes including the perspective towards pilot and production scale
- industry relevant process know-how in the fields of electro- and photochemistry, the synthesis and use of reactive intermediates, and nanoparticle synthesis
- industry relevant know-how in encapsulation of active ingredients and formulation technology
- special sensor technology

Chemistry

The chemical and pharmaceutical industry need to evolve and adapt themselves constantly to changing market conditions. These include an increasing commoditization of chemical products, a changing raw material base and climate change directly linked to the context of energy transition. Moreover, society increasingly voices the expectation that production and consumption need to become more resource-saving, environmental friendly, socially acceptable, in total, more sustainable and in some cases even on-demand. Chemical industry is the base of many value chains and often the most important driving force for innovations in other fields. As Europe's most important chemical producer, Germany especially faces the public as well as competitive pressure to establish a sustainable chemistry.

The Business Field Chemistry deals with the improvement and sustainable design of chemical production processes using in-house technologies. These technologies enable precisely controlled continuous chemical processes with increased process safety and resource and energy efficiency. Moreover they allow the preparation of materials with tailor-made properties and their formulation in reproducible quality. They foster decentralized, modular and flexible production concepts e.g. facilitating the adaptation to a raw material base changing towards more renewables. Sustainability is especially addressed by using regeneratively produced excess electricity to synthesize valuable chemicals with high efficiency and selectivity applying electrochemical microreactors. Photochemical microreactors with optimized use of light allow for green paths in organic synthesis and the utilization of carbon dioxide. The business field activities are round-up by specialized sensor technology for environmental and process monitoring.

Services provided for our customers and partners cover feasibility studies, lab chemical process development in the area of flow chemistry and formulation, the development and realization of specialized flow reactors (with an increasing use of additive manufacturing technologies) up to production scale and of sensor technology, and further support in transferring the results in chemical production and application e.g. by the establishment of demonstrators at pilot scale level.



What makes us unique?

- the breadth and depth of our microfluidic system competence for the automated preparation and analysis of human samples
- extensive experience in the miniaturization of lab preparation methods, their integration with microsystems, including measurement methods for sample analysis, such as PCR, nucleic acid extraction and purification, immunoassays or ELISAs and flow cytometry
- the capability to isolate and position single cells directly from billions of other cells
- a technique for the dispensing of single cells guaranteeing a good morphological quality and allowing a further cultivation of these cells

Diagnostics

The cause, course and treatment of a disease such as cancer, autoimmune disorders, diseases of the central nervous and the respiratory system, are significantly influenced by individual genetic attributes and living conditions. Modern medicine increasingly recognizes and addresses these differences between human individuals and terms this concept ‘personalized medicine’. Due to the tumor heterogeneity personalized approaches are especially relevant for cancer therapy. This is as well reflected in the “national decade against cancer” proclaimed by the German federal government to set the focus on the uniqueness of every human individual. Patients are expected to significantly benefit from precisely targeted therapies based on a personalized initial and companion diagnosis and a quasi-continuous monitoring of disease progression.

For more than two decades Fraunhofer IMM develops technical solutions for microfluidic-based analysis systems to be applied in life sciences, medical research/diagnosis and biological media analysis comprising the detection of pathogens in natural body fluids (such as whole blood, plasma, serum, sputum and urine), industrial media and water as well as the analysis of organic samples. Microfluidics enables robust solutions with new functionality and offers opportunities for significantly saving costs and time in (diagnostic) analysis processes. Our microfluidic processes and techniques allow to overcome limitations with respect to fast, locally available and precise diagnostic tests that still exist for near patient, on-site testing, operating inside and outside the established large central laboratories. The approaches enable the provision of in-depth diagnostic parameters that are so far unused. The importance for such an improved, fast and flexible diagnostic testing became directly obvious during the Corona crisis. Sample preparation is a vital part of our activities when developing the corresponding microfluidic cartridges and functional systems. Besides, we also use microfluidics to enable automated on-line quality control of cell based processes. Among others this is required for the future automated production of advanced therapy medical products, which is a precondition to make such personalized medical products applicable and affordable on a large scale.

FEATURED RESEARCH GROUPS

While thin film technology and clean room processes have a long publicly designated tradition at Fraunhofer IMM back to the 1990s, the explicit anchoring of biological and medical topics in the organization chart did not take place until 2020 although the basic work in microfluidics is also done for more than 20 years now. To some extent the two groups "Special Sensor Technology" and "Infection and Cancer Diagnostics" reflect the Ying and Yang of Fraunhofer IMM, the dual drivers complementing each other: technological possibilities and profound application knowledge clearly addressing societal needs.

The mind behind: Stefan Schmitt

Stefan Schmitt has acquired his diploma degree in Physical Engineering from Fachhochschule Wiesbaden in 1997 and earned his degree in applied physics from Hochschule RheinMain in 2010. Starting out as a process engineer, he is now responsible for IMM's 750 sqm cleanroom and he is head of the Special Sensor Group.

Special Sensor Technology Group

The Special Sensor Technology group focusses on providing its customers and partners with high-quality, customer-specific components for sensor technology and micromechanics – very often for mechanically and radiation demanding environments.

In contrast to many other organizations the Fraunhofer IMM group keeps the threshold low even for small quantities while its ISO certification has shown to be helpful for proven quality and high process reproducibility.
The ten-member team serves customers in particular from industry and large-scale research relying on a high-quality and diverse process portfolio. This portfolio comprises coating processes (oxidation, PECVD, LPCVD, PVD, electroplating), etching processes (wet, RIE, Deep-RIE, plasma stripping), metrology (SEM, TEM, optical microscopy, tactile and optical structure measurement, UV-VIS spectroscopy, ellipsometry), lithographic processes (thin and thick layer coatings, mask aligner, spray and spin coating, laser direct writing) as well as various assembly and connecting technologies (gluing, wire bonding, wafer bonding, wafer probing).

Receiving funding from:

- Fusion4Energy: F4E-FPA-384 SG04
- European Commision: FETPROACT-01-2018 NeuHeart (#824071)

Major projects

- industrial helium leak detection: Continuous further development of a helium selective quartz membrane which is the basis for a commercial robust and precise helium sniffing leak detector used to detect very small leaks in all forms of pipe systems.
- development and provision of a crucial component for the German environmental satellite "EnMAP": its hyperspectral instruments use a high-precision double slit entry aperture that directs the incident light (visible to deep infrared) reflected from earth into two detectors allowing to achieve a 30 m resolution with 242 spectral bands. With tolerances of less than five micrometers assembly proved to be one of the major challenges.
- detectors for fusion research: development and fabrication of bolometers with high radiation and temperature resistance being used in many of the existing fusion reactors around the world.
- various probes for neuro surgery and for measuring heart activity.

The mind behind:
Dr. Christian Freese

2020 – present:
Fraunhofer IMM Mainz, Germany
Head of Group – Infection and Cancer Diagnostics
Project leader – Scientist

2017 – 2019:
Fraunhofer IMM Mainz, Germany
Project leader – Scientist

2015 – 2016:
University Medical Center Mainz, Germany
Institute for Pathobiochemistry, Prof. C. Behl
PostDoc position

2008 – 2015:
University Medical Center Mainz, Germany
Institute of Pathology, REPAIR-Lab,
Prof. C. J. Kirkpatrick
PhD Thesis and PostDoc position

2001 – 2007:
Johannes Gutenberg-University Mainz, Germany
Diploma in Biology

Infection and Cancer Diagnostics Group

Within the Infection and Cancer Diagnostics group biological engineering know-how meets cost-efficient microfluidics for the development of on-site applications.

Major projects

- establishment of an administrative and regulatory ecosystem for a scalable, intelligent and digitized open-access rapid test platform for the detection of pandemic infectious agents allowing to adequately balance individual freedom and protection.
- supporting SMEs with research capacities in the growing field of "single-cell-tools" during the times of COVID-19 and beyond by a virtual research campus aiming to be a one-stop-shop and single exchange point for SMEs engaged in this product segment.
- aiming to improve the sensitivity and efficiency of analytical systems by optimizing microstructured components and to demonstrate the potential of such systems for the fast and automated detection of viral infectious agents (e.g., SARS-CoV-2) via rapid PCR being as fast as an antigen rapid test but with significantly higher sensitivity and specificity.

Profound platform technologies form the basis for the rapid development of application-driven solutions to diagnostic problems in societally relevant subject areas. The focus lies on the three main topics liquid biopsy, PCR and protein-POC technologies and 3D printing of cells. Automated cell isolation, isolation and analysis of exosomes as well as the detection of freely circulating DNA support personalized infection and cancer diagnostics. Fast PCR systems, multiparameter/multiplex analysis and isothermal amplification are the key for rapid detection of COVID-19 and further infectious diseases. Defined cell-on-demand single cell dispensing and scalable cell trap arrays are required for tissue and organ printing. Relying on more than 10 years of experience in implementing microfluidic solutions the team has developed several unique selling points such as flexible solutions based on customizable platforms, partially integrated sample preparation and fast detection with low-cost components and consumables. A fully automated solution down to the single cell for cell analysis, characterization and cultivation, a patented method for the detection of cfDNA in whole blood samples as well as the ability to perform complex cell focusing and dispensing on easy-to-produce microfluidic cartridges complement the merits.

Receiving funding from:

- Sondervermögen Rheinland-Pfalz zur nachhaltigen Bekämpfung der COVID-19 Pandemie (RESCUE-SEPS)
- State of Rhineland Palatinate funded with the framework of the "europäischen Fonds für regionale Entwicklung (EFRE REACT-EU)" (OPEN-POCT, FAST-MOPPS)
- Federal Ministry of Education and Research Germany (Photox und EPI-CARE)
- Horizon2020 (ELEVATE)
- Fraunhofer internal programs (VaMoUS)
- Fraunhofer „Pioneer-Projekt Wissenschaftsraum" (Speed-Vac)

PEOPLE MAKE THE DIFFERENCE

Our employees are the backbone of our institute – they make the difference. Their experience, knowledge, collective responsibility and subjective well-being determine our scientific and economic success. We believe that success best comes from interdisciplinary teams working together at eye level with perception and appreciation. For this reason, we focus on diversity, the creative potential of all genders, different ages, cultures and disciplines. To protect the health of our team members, we are setting high standards for occupational safety and the quality of the working environment and workplaces.

Michael Eberhard

»I am an automation engineer. For 30 years, I have been digitizing mainly process engineering plants up to infrastructure projects of international importance. In concrete terms at IMM, this means working together in an interdisciplinary team to find out the best way to operate a process or component and then collecting as much data as possible from it (Big Data). These then form the basis for automatic and intelligent process control, all the way up to a cyber-physical system (CPS). The resulting efficiency of a process plant is an important contribution to sustainability.

We have many trend-setting technologies at IMM. I would like to contribute my wealth of experience to make our processes smart, stable, safe, highly efficient and as easy to operate as a coffee machine. I believe that is what excites our customers. I like working at IMM because I find the environment and the collaboration with other researchers very inspiring.«

Zlatko Didovic

»I have been an employee of the "Mechanical Workshop" for over 24 years and I am working in the field of electrical discharge machining. My main tasks include the contactless machining of components (component generation, post-processing and technology development). After receiving an order, I use drawings and data files, which I combine in a CAD system with technology parameters and my manufacturing strategy. Especially challenging are individual parts or assemblies that have already experienced value addition and do not allow machining attempts. Equally exciting are the smallest components, the manufacturing process of which can only be implemented with many years of experience and which have, in the end, amazed many industry experts.

What is particularly motivating is that I can shape and implement my own ideas for component fabrication in consultation with the clients. In doing so, I gain new experience, which I can, in turn, combine and apply with new tasks. Equally motivating is the fact that I get to work with machines, materials and equipment from leading manufacturers, and that, from time to time, I get the chance to push those technological boundaries (feasibility and size) I had learned before to be the limit.«

Stefan Schmitt

»I have been working in the institute for more than 25 years – and now I am leading the Special Sensors Group. From a technical point of view, my task is to link the requirements of our customers to our silicon-based micro manufacturing capabilities and develop, together with our process experts, new technical processes and process chains in order to facilitate new sensor approaches.

This development is a creative task and I benefit from the large number of processes available within the institute, as well as from the concise know-how of our employees. I have to constantly adapt to very different topics, as my customers come from various fields, such as medical technology, aerospace or industrial metrology. Together with the interdisciplinary backgrounds of my internal and external customers, the work never gets boring.«

Tobias Weißenberger

»I am working on the development and optimization of catalysts tailor-made for the processes used in the energy division at IMM. My tasks include experimental work such as investigation of catalyst performance and catalyst characterization, but I also keep up with the relevant literature to find new catalyst formulations. Furthermore, I evaluate and interpret the experimental data and prepare the results for presentation at meetings or publication in peer-reviewed journals.

I very much enjoy the varied tasks and challenges of working in an applied research environment. What I like especially about working at IMM is the interdisciplinary approach, the close collaboration with colleagues in other disciplines and that I can make a contribution towards sustainable processes for decentral hydrogen generation.«

Nils Weber

»In my administrative role in the Purchasing / Finance group, one of my main tasks is to procure goods and services in compliance with procurement law. I advise our scientific and technical colleagues on the preparation of lists of services and carry out invitations to tender based on these. In addition, I act as a customs representative for imports at the IMM. I clarify all questions in the area of customs clearance and declare the corresponding imports to the customs authorities in cooperation with the purchasers.

My work at the IMM is very multifaceted, so I have the opportunity to familiarize myself with a wide variety of topics. That, coupled with this year's system switch to SAP, hardly allows for routine, so every day brings new challenges.«

Verena Grützner

»I am member of the Group Infection and Cancer Diagnostics. Our research focuses on innovative solutions in the area of medical diagnostics, but also for food industry and in the environmental field. My role is to devise, acquire and realize projects that generally share the overall aim of a miniaturized, automated and beyond state-of-the-art analysis. Moreover, I am authorized and responsible for safety and infection prevention of R&D activities involving infectious pathogens at IMM.

I very much enjoy the variety of the projects in interdisciplinary collaboration with internal and external partners, and the diverse application fields addressed. This means, continuously new challenges and experiences that are in line with the spirit of the time and present needs (e.g. SARS-CoV-2 diagnostics), as well as scientific advancement. Finally, I feel and appreciate an open and supportive environment and a wide scope for creativity at IMM, offering the chance to develop and realize own ideas and visions.«

Lisa Pokropp

»As the illustrator of the communication unit, my main task is to visually support the work of our scientists. I always try to use the best medium to convey their ideas. This may be 2D illustrations for papers, 3D visualizations for effect or small animated videos to get the point across.

What motivates me, is that my drawings can take at least a little part in meaningful science. Due to the many different projects at the IMM my work is very varied and almost never gets boring. And the happy faces are very rewarding when people realize they don't have to spend additional hours in Powerpoint to create some kind of explanatory visual, because they can just tell me and I'll realize it.«

LIFE IS MOVING IN

In the annual report 2015 we presented the vision to have an extension building for the first time under the headline “More Space for Future”. From that point on, two pages on the subject of the extension building were a permanent feature in the report. As we all know, even the best features come to an end. And so, these two pages, presenting our employees at work in the new premises, will be the last being explicitly dedicated to this topic. So, dare to take a first look over our shoulder and stay curious about our development results, which we will owe in part to the new opportunities created by this building.

PROFILE

Fraunhofer Institute for Microengineering and Microsystems

Based on existing societal challenges and driven by sustainable development goals Fraunhofer IMM focusses the majority of the workforce as R&D service provider, across the divisions **ENERGY, CHEMISTRY** and **DIAGNOSTICS,** on the topics of **CLEAN ENERGY, SUSTAINABILITY** and **HEALTH.** Thereby we rely on our fundamental core competencies in **MATERIALS, TECHNOLOGIES, PROCESSES** and **ENGINEERING.** Following our roots, we apply fundamental processes based on microstructure technology wherever they are target-oriented.

The **MATERIALS** competence comprises our very profound knowledge about chemical and biological compounds, their utilization and synthesis, their properties and their potential application fields. It includes our knowledge about materials, their properties and processing as well as their suitability for various applications.

The **TECHNOLOGIES** competence comprises our very profound knowledge about machining, processing, detection and analytical methods. It includes decades of experience in optimized operation parameters as well as suitable application scenarios for each of these technologies.

The **PROCESSES** competence comprises our ability to perform the translation of concepts into devices or entire systems essentially required for fulfilling any single kind of operation. It is about our application related knowledge of processes in various disciplines as well as our ability to perform the physical construction work.

The **ENGINEERING** competence comprises our higher-level engineering abilities used to initiate, design, develop, fabricate and realize a process or system reaching the required level of integration, functionality and complexity.

Very similar to the organic bases of the DNA the unique combination of these core competencies makes us what we are and allows us to provide our customers and partners with system and technology oriented innovations, solutions that contribute to their competitiveness and provide value for their businesses.

The **CLEAN ENERGY** topic translates into solutions for hydrogen-based energy supply, power-to-chemicals, ammonia utilization and radiation monitoring.

The **SUSTAINABILITY** topic translates into solutions for flow chemistry-based process intensification, decentralized production concepts for chemicals, environmental monitoring and process monitoring.

The **HEALTH** topic translates into solutions for infection diagnostics, liquid biopsy and single cell analysis, biological media analysis and nanoparticle systems for therapeutic and diagnostic as well as industrial applications.

Our goal always is
TO MAKE A DIFFERENCE.

Quality Policy

The Fraunhofer IMM management level stipulates our quality policy and ensures a consequent implementation of the quality management system. We are currently certified according to DIN EN ISO 9001:2015 and review the effectiveness of our quality management system by regular internal audits and quality meetings. Our quality goals are set to continuously increase customer satisfaction and to improve our process performance.

Who we are and what we expect from ourselves

We are the leading contract research organization providing research and development services to our customers and partners from industry, other research organizations and universities.

We provide solutions for partially complex problems. Thus, usually our services cannot be low cost but they are always worth their price. And we do our best at all times to meet or exceed the expectations and demands placed on us relying on a reproducibly high quality of our work.

Our employees are the backbone of our institute. Maintaining adequate communication structures, training and qualification opportunities as well as a positive and productive working environment is our continuous effort.

How we work

We are developing solutions with and for industry on direct order. But we are as well working together with our customers and partners in projects being co-financed by the federal government, the federal state of Rhineland-Palatinate or the European Commission in order to tackle important societal challenges.

We are a reliable and loyal partner cultivating fair relationships to customers and suppliers, communicating openly and honestly with all stakeholders to establish constructive long-term collaborations.

We strive for a project-oriented continued development of our capabilities. Quality-determining process flows are clearly defined, documented and are continuously adapted to changing requirements and improved. Novel quality-determining processes are documented immediately. All related documents are clearly guided and controlled in order to guarantee a sustainable quality in all areas. Our quality awareness and understanding as well as the attitude of all employees towards quality are essential for the satisfaction of our customers. Our employees feel fully committed to our standards of quality and are being encouraged to further expand our high standards in project work and quality of service by continuous training.

The value we create

- We transfer requirements into workable and customer-friendly solutions
- We secure a competitive edge and a head start in innovation
- "We boldly go where no one has gone before": We accept challenges others don't due to lack of interest or lack of knowledge/experience

The Fraunhofer IMM in Numbers (2021)

97 %
Operational Spending

3 %
Capital Spending

7.3
Million Euro
Contract Research

< 49 % Public

> 51 % Industrial

125 **Projects**

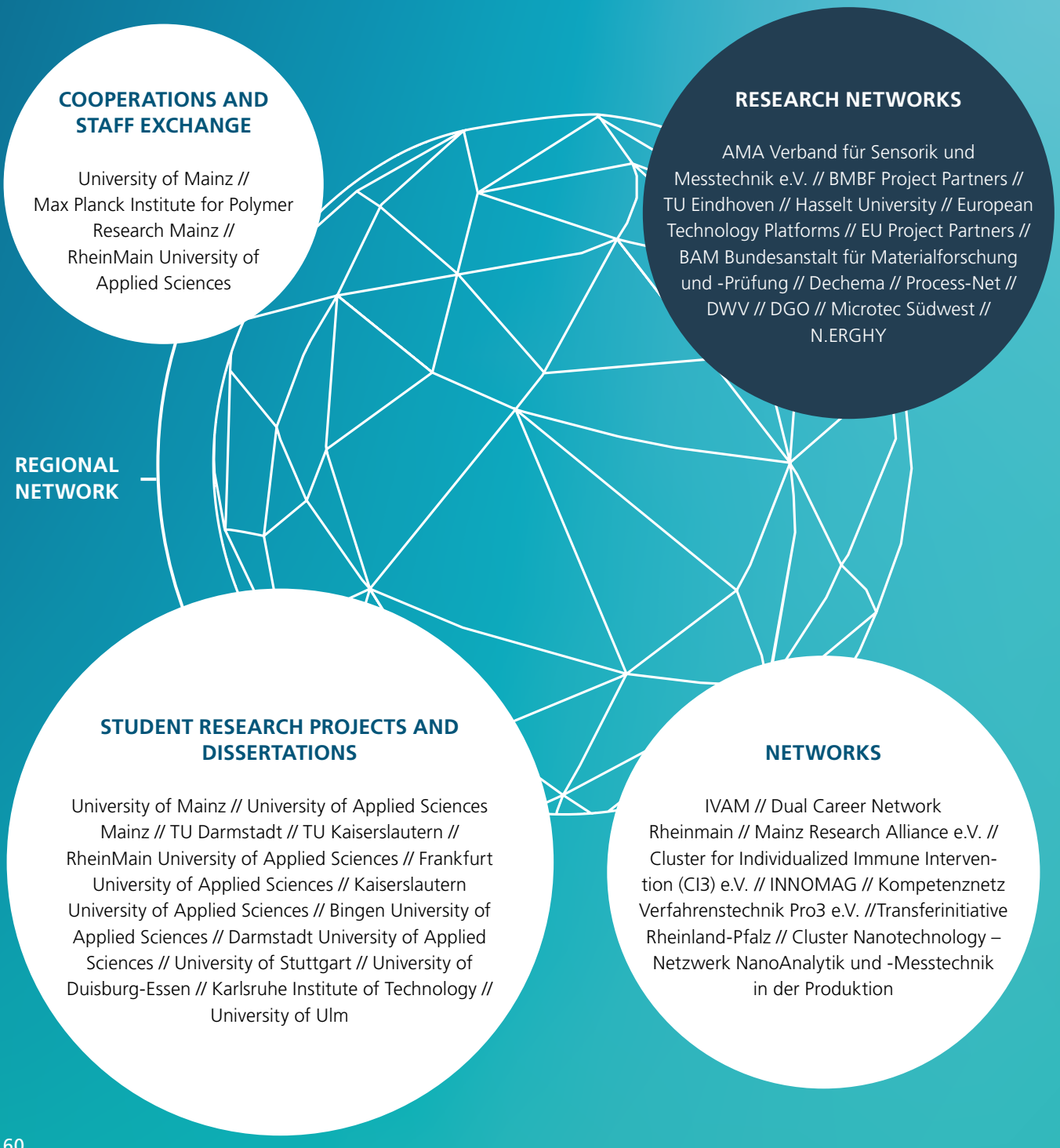
Revenues From External Funding Sources

78.3 %
Publicly Financed R&D Projects

21.7 %
Industrially Financed R&D Projects

Fraunhofer IMM Network

In order to secure our competitiveness and scientific excellence, a close cooperation with research institutes and multipliers is of particular importance to us. Our scientists and engineers therefore cooperate with universities, institutes and companies both nationally and internationally in development projects with a short-term and long-term focus. Close connections to partners in the region are of special relevance in this process.



Associations and Alliances

within Fraunhofer

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft based in Germany is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. It is a trailblazer and trendsetter in innovative developments and research excellence.

The Fraunhofer-Gesellschaft supports research and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

The Fraunhofer-Gesellschaft's interdisciplinary research teams turn original ideas into innovations together with contracting industry and public sector partners, coordinate and complete essential key research policy projects and strengthen the German and European economy with ethical value creation. International collaborative partnerships with outstanding research partners and businesses all over the world provide for direct dialogue with the most prominent scientific communities and most dominant economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees, predominantly scientists and engineers, work with an annual research budget of €2.9 billion. Fraunhofer generates €2.5 billion of this from contract research. Industry contracts and publicly funded research projects account for around two thirds of that. The federal and state governments contribute around another third as base funding, enabling institutes to develop solutions now to problems that will become crucial to industry and society in the near future.

The impact of applied research goes far beyond its direct benefits to clients: Fraunhofer institutes enhance businesses' performance, improve social acceptance of advanced technology and educate and train the urgently needed next generation of research scientists and engineers.

Highly motivated employees up on cutting-edge research constitute the most important success factor for us as a research organization. Fraunhofer consequently provides opportunities for independent, creative and goal-driven work and thus for professional and personal development, qualifying individuals for challenging positions at our institutes, at higher education institutions, in industry and in society. Practical training and early contacts with clients open outstanding opportunities for students to find jobs and experience growth in business and industry.

The prestigious nonprofit Fraunhofer-Gesellschaft's namesake is Munich scholar Joseph von Fraunhofer (1787–1826). He enjoyed equal success as a researcher, inventor and entrepreneur.

Figures as of: January 2022

The Fraunhofer-Gesellschaft in Numbers (2021)

2.9
Billion Euro Research Budget

76
Institutes and Research Units in Germany

>30,000
Staff

2.5
Billion Euro Contract Budget

APPENDIX

Fairs, Events and Conferences

Fair/Event/Conference	Date	Type of Event
Online seminar „Power-to-chemicals – Microreactor based flow electrochemistry for sustainable syntheses"	07.07.2021	Virtual presentation
IVAM Hightech Summit 2021	25./26.08.2021	Virtual conference
Online seminar „IMM hydrogen technologies – logistic hydrogen carriers for a sustainable future"	01.09.2021	Virtual presentation
20. Mainzer Wissenschaftsmarkt	11./12.09.2021	Virtual event
„SiCellNet" Online Workshop	21.09.2021	Virtual Workshop
Young Scientists' Workshop at IMM	28.09.2021	Virtual Workshop
FC Expo 2021	29.09.-01.10.2021	Virtual fair
Online seminar "Microfluidic polymer cartridges: Development and realization"	06.10.2021	Virtual presentation
Online seminar "Microfluidic solutions for POC testing - basis for new concepts to prevent the spread of infectious diseases"	04.11.2021	Virtual presentation
Online seminar "Ammonia: Smarter hydrogen for decarbonization?"	08.12.2021	Virtual presentation
Online seminar "Organometallics in flow: From research results to applications"	02.03.2022	Virtual presentation
Hydrogen Online Workshop 2022	03.03.2022	Virtual conference
Transfertag "Zeitenwende Elektromobilität?"	24.03.2022	Virtual event
Online seminar "Methanol as a sustainable hydrogen carrier"	30.03.2022	Virtual presentation
LNG & Future Fuels Forum	07.-09.04.2022	Conference, Hamburg
ISGC 2022	16.-20.05.2022	Conference, La Rochelle
THE REGATEC 2022	17.-18.05.2022	Conference, Malmö
microTEC Südwest Clusterkonferenz 2022	18./19.05.2022	Conference, Freiburg
EHEC 2022	18.-20.05.2022	Conference, Madrid
Hannover Messe 2022	31.05.-02.06.2022	Trade fair, Hannover
German Biotechnology Days 2022	04.05.2022	Conference, Hamburg
analytica 2022	21.-24.06.2022	Trade fair, München
Online seminar in context of the EU INCITE project „Flow Chemistry – selected aspects of process and reactor development for industrial implementation"	23.06.2022	Virtual presentation
55. Jahrestreffen Deutscher Katalytiker	27.-29.06.2022	Conference, Weimar


Making the difference: Medical diagnostics and automated analysis of biological parameters
Medical diagnostics

Communication Highlights

For the first time in the annual report, we want to take a very brief look behind the scenes of communication. As a small institute, we were able to achieve a very good communication reach in 2021 with a fair contribution to the Fraunhofer strategic research fields.

In August 2021 we could release the first issue of our internal newsletter, currently working on issue #4. And, last but not least, the early summer of this year gave us the first summer party for all our employees after more than two years now.

Summerparty
2022

Internal
Newsletter

Press Reach
2021

92 Contributions
Published

23 Mio
Contacts reached

of which
58 are in **Fraunhofer Strategic Fields**

- Bioeconomy
- Artificial Intelligence (AI)
- Hydrogen Technologies
- Resource Efficiency and Climate Technologies

Publications 2021/2022

PUBLICATIONS IN REFEREED JOURNALS

Authors	Title of Publication
Baki, A.; Wiekhorst, F.; Bleul, R.:	ADVANCES IN MAGNETIC NANOPARTICLES ENGINEERING FOR BIOMEDICAL APPLICATIONS - A REVIEW In: Bioengineering 8 (2021) 10, 134
Allelein, S.; Aerchlimann, K.; Rösch, G.; Khajehamiri, R.; Kölsch, A.; Freese, C.; Kuhlmeier, D.:	PROSTATE-SPECIFIC MEMBRANE ANTIGEN (PSMA)-POSITIVE EXTRACELLULAR VESICLES IN URINE—A POTENTIAL LIQUID BIOPSY STRATEGY FOR PROSTATE CANCER DIAGNOSIS? In: Cancers 14 (2022) 12, 2987
Kolb, G.; Keller, S.; Neuberg, S.; Schürer, J.; Tiemann, D.; Valenteijn, H.; Wichert, M.; Zapf, R.:	A COMPLETE FUEL PROCESSOR FOR PROPYLENE GLYCOL AS HYDROGEN SUPPLY FOR A 5 KW LOW TEMPERATURE PEM FUEL CELL – INTERIM REPORT ON SINGLE REACTORS AND SYSTEM PERFORMANCE In: Catalysis Today 383 (2022), 183-192
Danilov, V.A.; Hofmann, C.; Kolb, G.:	2D MODEL OF TRANSFER PROCESSES FOR WATER BOILING FLOW IN MICROCHANNEL In: ChemEngineering 5 (2021) 3, 42
Neumann, C.; Bacher, L.; Musyanovych, A.; Tutus, M.; Latnikova, A.:	FORMULATION OF NEXT-GENERATION MULTICOMPARTMENT MICROCAPSULES BY REVERSIBLE ELECTROSTATIC ATTRACTION In: Chemistry - A European Journal 27 (2021) 36, 9336-9341
Gribko, A.; Stiefel, J.H.; Liebetanz, L.; Nagel, S.M.; Künzel, J.; Wandrey, M.; Hagemann, J.; Stauber, R.H.; Freese, C.; Désirée Gül:	ISOMAG—AN AUTOMATED SYSTEM FOR THE IMMUNOMAGNETIC ISOLATION OF SQUAMOUS CELL CARCINOMA-DERIVED CIRCULATING TUMOR CELLS In: Diagnostics 11 (2021) 11, 2040
Stiefel, J.H.; Freese, C.; Sriram, A.; Alebrand, S.; Srinivas, N.; Sproll, C.; Wandrey, M.; Gül, D.; Hagemann, J.; Becker, J.C.; Baßler, M.:	CHARACTERIZATION OF A NOVEL MICROFLUIDIC PLATFORM FOR THE ISOLATION OF RARE SINGLE CELLS TO ENABLE CTC ANALYSIS FROM HEAD AND NECK AQUAMOUS CELL CARCINOMA PATIENTS In: Engineering in Life Sciences 22 (2022) 5, 391-406
Lüdicke, M.; Hildebrandt, J.; Schindler, C.; Sperling, R.A.; Maskos, M.:	AUTOMATED QUANTUM DOTS PURIFICATION VIA SOLID PHASE EXTRACTION In: Nanomaterials 12 (2022) 12, 1983

PUBLICATIONS IN OTHER JOURNALS

Authors	Title of Publication
Fuhrmann, M.; Musyanovych, A.; Thoelen, R.; Möbius, H.:	DETERMINATION OF THE DIELECTRIC CONSTANT OF NON-PLANAR NANOSTRUCTURES AND SINGLE NANOPARTICLES BY ELECTROSTATIC FORCE MICROSCOPY In: Beilstein Archiv (2022), 202233
Stiefel, J.H.; Freese, C.:	TROPFEN FÜR TROPFEN GEGEN KREBS In: Laborpraxis (2022), ID:47923484
Menges-Flanagan, G.:	REAKTIVE INTERMEDIATE: SKALIERBARER MIKROREAKTOR FÜR GRIGNARD-REAGENZIEN In: Verfahrenstechnik (2022) 3, 16-1

CONTRIBUTIONS TO BOOKS

Authors	Title of Publication
Rehm, T.H.:	PHOTOCHEMISTRY IN FLOW FOR DRUG DISCOVERY In: Flow Chemistry in Drug Discovery, Part of the Topics in Medicinal Chemistry book series (TMC, volume 38); Alcázar, J.; de la Hoz, A.; Díaz-Ortiz, Á. (Ed.): Springer, Cham, 2021, 71-120; ISBN: 978-3-030-85591-8
Kolb, G.:	FUEL PROCESSING FOR FUEL CELLS AND ENERGY RELATED APPLICATIONS In: Hydrogen Production and Energy Transition - Volume 1; Van de Voorde, M. (Ed.) - Berlin, Boston: de Gruyter, 2021, 469-492; ISBN: 9783110596229
Groos, U.; Semmel, M.; Schaadt, A.; Bürger, S.; Horch, F.; Geiling, J.; Öchsner, R.; Kolb, G.; Köhler, J.: Allelein, S.; Aerchlimann, K.; Rösch, G.; Khajehamiri, R.; Kölsch, A.; Freese, C.; Kuhlmeier, D.:	EINSATZ VON WASSERSTOFFTECHNOLOGIEN IN MOBILITÄT UND TRANSPORT In: Wasserstofftechnologien; Neugebauer, R. (Ed.) - München, Deutschland: Springer Vieweg, 2022, 123-153; ISBN: 978-3-662-64834-6
Metz, S.; Smolinka, T.; Bernäcker, C.I.; Loos, S.; Rauscher, T.; Röntzsch, L.; Arnold, M.; Görne, A.L.; Jahn, M.; Kusnezoff, M.; Kolb, G.; Apfel, U.-P.; Doetsch, C.:	WASSERSTOFFERZEUGUNG DURCH ELEKTROLYSE UND WEITERE VERFAHREN In: Wasserstofftechnologien; Neugebauer, R. (Ed.) - München, Deutschland: Springer Vieweg, 2022, 207-258; ISBN: 978-3-662-64834-6

PUBLICATIONS IN PROCEEDINGS

Authors	Title of Publication
Gül, G.; Baßler, M.:	SCALABLE MULTILEVEL QUANTIZATION FOR DISTRIBUTED DETECTION In: ICASSP 2021 - IEEE International Conference on Acoustics, Speech and Signal Processing: IEEE, 2021, 5200 - 5204; ISBN: 978-1-7281-7606-2
Schwarz, N.; Baßler, M.; Walther, T.; Klotzbücher, T.:	DIRECT LASER WRITING OF METAL NANOSTRUCTURES FROM THE GAS PHASE BY TWO-PHOTON ABSORPTION PROCESS In: Proceedings - Lasers in Manufacturing Conference (LiM; 21.-24. Juni 2021) : Wissenschaftliche Gesellschaft Lasertechnik e.V., 2021, 1 - 9
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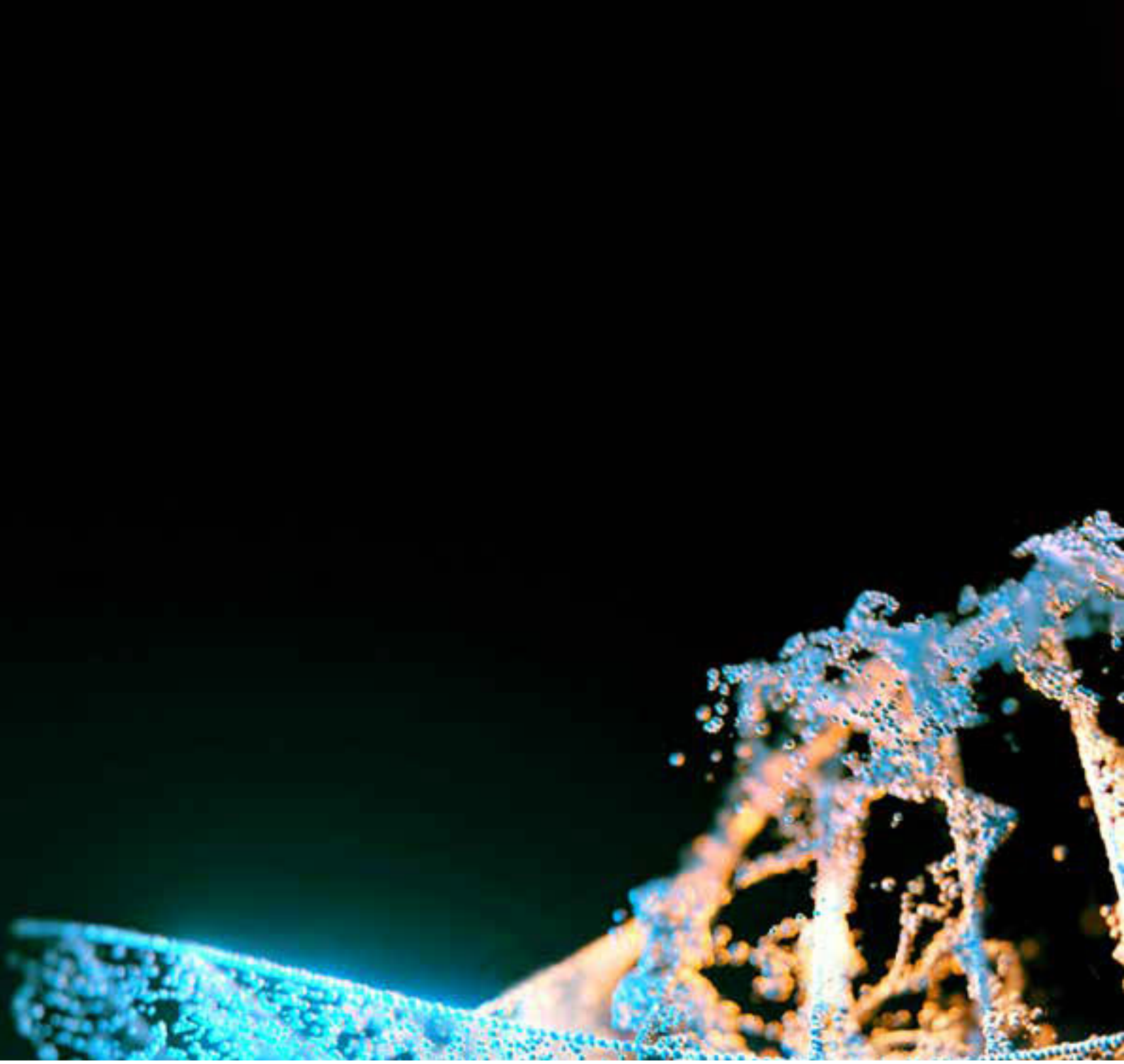

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