Fraunhofer
IMM

# Making the Difference – for People

**Annual Report 2022/23**


## Contact

Fraunhofer Institute for
Microengineering and Microsystems IMM
Tel. +49 6131 990-0
Fax +49 6131 990-205
info@imm.fraunhofer.de

Fraunhofer IMM
Carl-Zeiss-Strasse 18–20
55129 Mainz | Germany
www.imm.fraunhofer.de


Fraunhofer IMM / Annual Report 2022/23

**Fraunhofer Institute for Microengineering and Microsystems IMM**

# Making the Difference – for People

**Annual Report 2022/23**

# Editorial Notes

**Editorial Team**
Dr. Stefan Kiesewalter
Antonia Winkler
Lisa Pokropp
Tobias Hang

**Layout and Design Concept**
Ines Oliveira

**Production**
O.D.D. GmbH & Co. KG Print + Medien
www.odd.de

**Editorial Deadline**
06 / 2023
Information on fields of research and detailed contacts are available on both the German and English versions of the Fraunhofer IMM website: www.imm.fraunhofer.de

**Photo Acknowledgements**
title/cover, page 2–3, 6, 71: Orbon Alija / iStock
illustrations at pages 8–11, 13, 22, 31, 36, 37, 47, 49, 50–53, 59–61, 63: Lisa Pokropp, Fraunhofer IMM
pages 18–21, 23–31, 39–41, 47, 49, 56, 67, 69: Tobias Hang, Fraunhofer IMM
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**Editorial Address**
Fraunhofer Institute for
Microengineering and Microsystems IMM
Carl-Zeiss-Strasse 18 – 20
55129 Mainz | Germany

Phone +49 6131 990-0
Fax +49 6131 990-205

info@imm.fraunhofer.de
www.imm.fraunhofer.de



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# Contents

# DEAR READERS

Can science make a difference? **Making the difference – for people** has always been the driving force behind our work. Looking at our past and current projects, it becomes clear: In the end, our scientific work was and is (almost) always about a tangible benefit for us humans.

Be it new treatments against cancer or new diagnostic possibilities, research into renewable energies or improvements for the chemical industry – without scientific knowledge, all this and much more would not be possible. Science creates knowledge – a commodity that is rightly becoming increasingly important in our society. According to UNESCO, science should serve all of humanity and help create a deeper understanding of nature and society, a better quality of life, and a sustainable and healthy environment for present and future generations.

With this credo in mind, a good portion of curiosity and thirst for knowledge as well as a professional environment, our employees in the fields of energy, chemistry and diagnostics research and develop sustainable solutions. $CO_2$ avoidance through the safe use of ammonia, the encapsulation of seeds to protect them from environmental influences, or a platform technology for monitoring water and food quality are just a few examples of our portfolio.

To make a difference in your daily work, to do something better or even to be able to think something completely new, you often have to change your perspective – "zoom out" to see the big picture. For the actual implementation, we "zoom in" again to work with the smallest structures wherever necessary in the field of microtechnology. We have also let this interaction be reflected in the report.

Accompany us through our year, zoom out and back in and get an overview for yourself of what Fraunhofer IMM does for each and every one of us. Because we are sure: we make a difference.

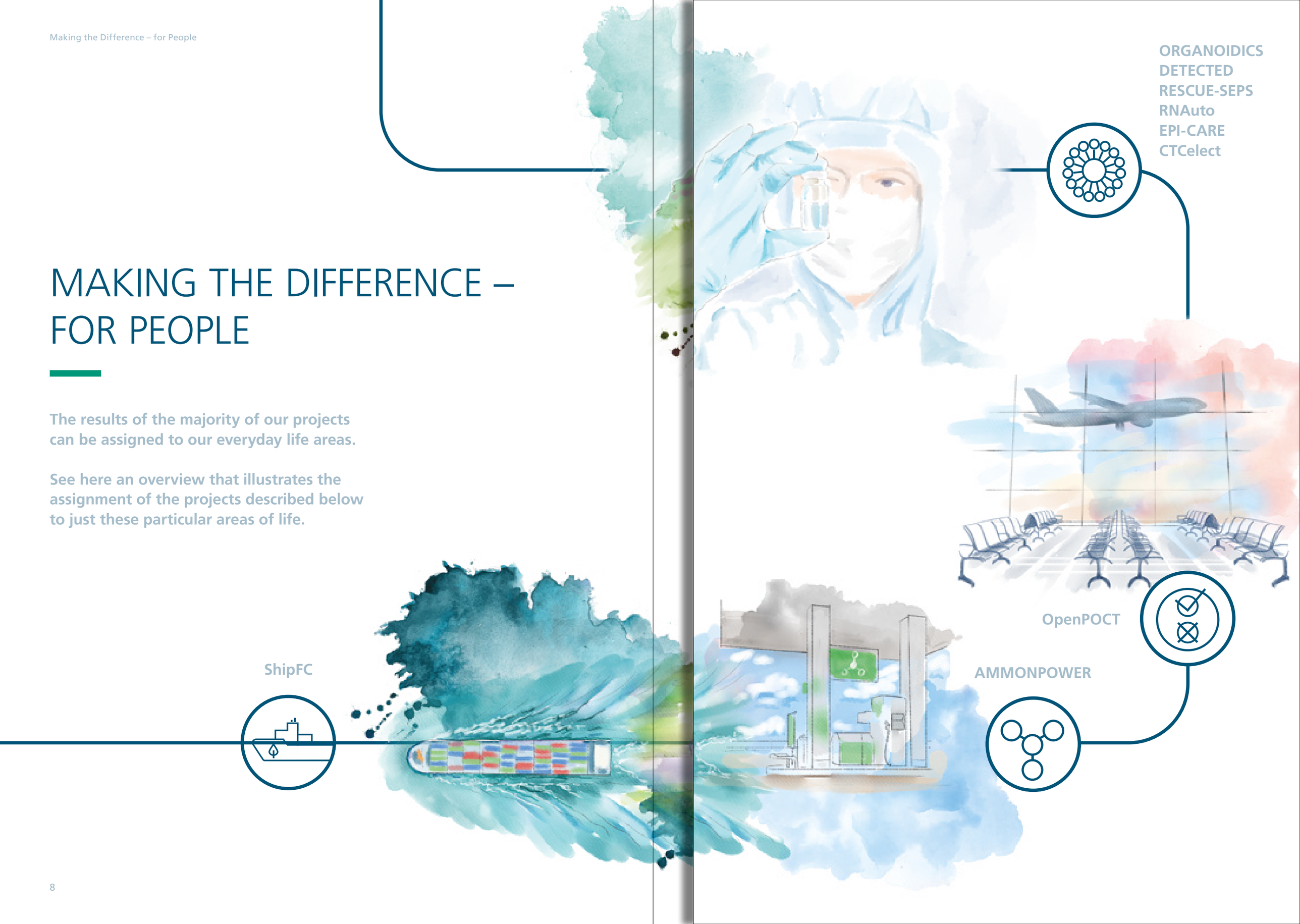
I hope you enjoy reading,

Prof. Dr. Michael Maskos
Executive Director, Fraunhofer IMM

# MAKING THE DIFFERENCE – FOR PEOPLE

**The results of the majority of our projects can be assigned to our everyday life areas.**

**See here an overview that illustrates the assignment of the projects described below to just these particular areas of life.**



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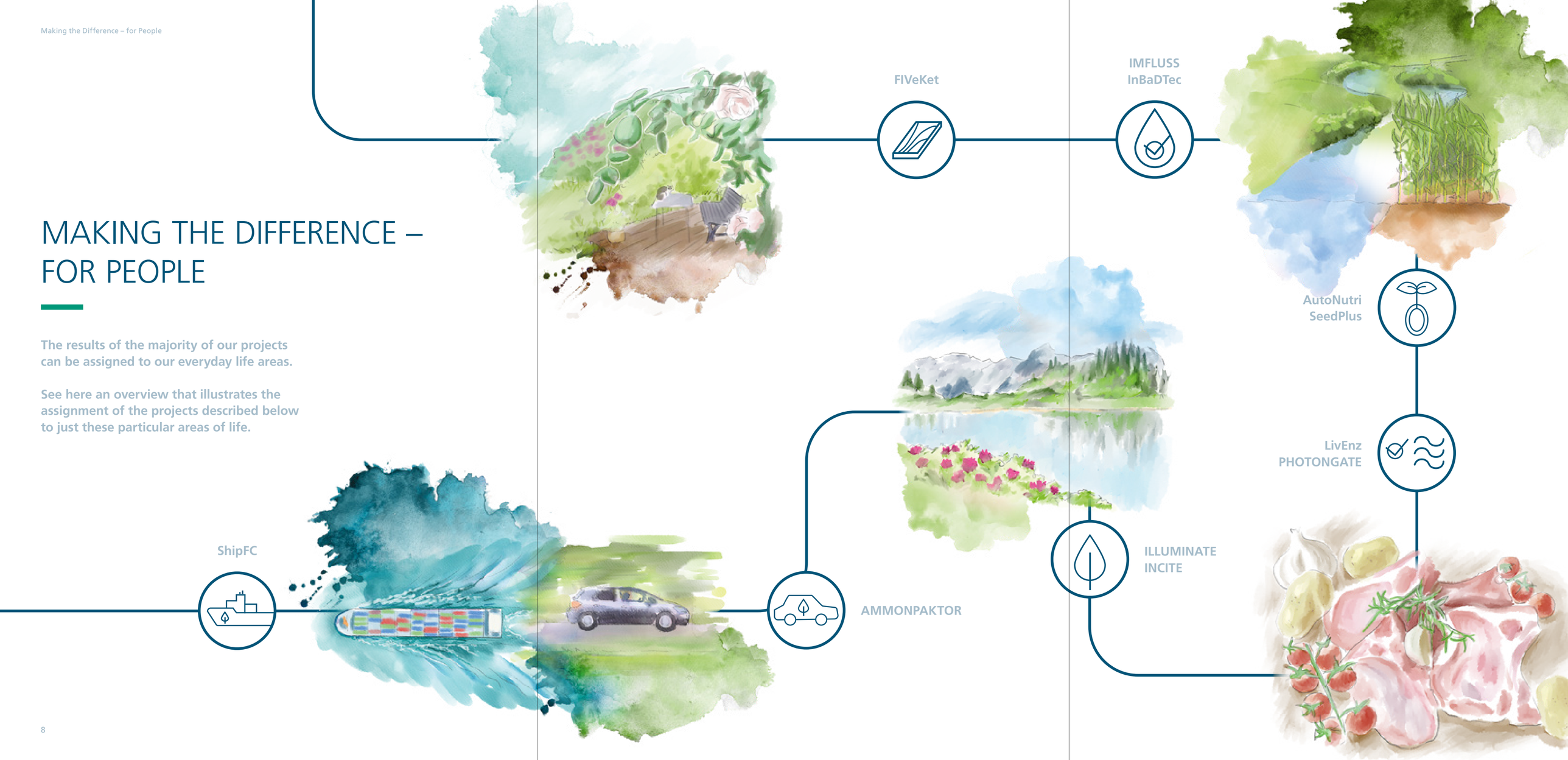


# FLAGSHIP PROJECTS

**The Flagship Projects are outstanding representatives for the capabilities of microsystem technology allowing to make a real difference in real-world applications.**

## 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:** Work within the last year has focused on improving engineering aspects of the pilot set-up with the goal of establishing a second generation piloting set-up at an industrial partner's site increasing the Technological Readiness Level (TRL) from 6 (technology demonstrated in relevant environment) to 7 (system prototype demonstration in operational environment).

After moving the existing pilot set-ups into the dedicated walk-in fume hood in the new building, extensive piloting efforts for Mg as well as Zn based organometallic reagents have been undertaken to not only enlarge the portfolio of accessible reagent but also gain further processing insight to be fed back into the improvement of engineering aspects of the piloting set-ups as mentioned above.

The product portfolio itself has been enlarged to now encompass about 20 reagents each for Mg and Zn based organometallic reagents of which a significant number has not only been established on the laboratory but also on the pilot scale (up to about 18 l/h).

*The basic information: https://www.imm.fraunhofer.de/en/divisions/division-chemistry/reactive-intermediates.html*

## Power-to-Chemicals – Microreactor-based Electrolysis

**THE GOAL:** Moving green synthesis routes starting from renewable raw materials and using sustainably generated electric current as reagent for a sustainable production of chemicals to industrial scale.

**THE STATUS:** Our flexible and scalable electrochemical microreactor concept as core element for the realization of a green synthesis process has been adjusted to the specific needs of the Kolbe electrolysis of carboxylic acids to fatty alkanes as reference process. The starting material carboxylic acids thereby can be obtained from biomass and represents a platform chemical to obtain solvents, fuels, fine chemicals, lubricants, and polymers. Targeting finally an industrial implementation, focus of the activities within the last year have been to validate and demonstrate the scaling concept of the used reactor and process technology for higher throughput ranges. The iterative further development of a corresponding pilot plant has led to increased investigation possibilities: while in lab scale 2–4 electrochemical cells operated in parallel could be investigated in single-pass mode, it is now feasible to increase cell number to 10–20 and to operate them not only single-pass mode but also in a recirculation mode regarding the electrolyte flow. With the 10 cells configuration at a current of 410 ampere and an electrolyte throughput of 18 l/h a productivity for targeted Kolbe products of 0.85 kg/h in single-pass mode could be obtained. Aside demonstrating the validity of the scaling-approach, also the operation at high throughput rates has been demonstrated laying a solid base for future cooperations with industry towards implementing electrochemical processes in production scale.

*The basic information: https://www.imm.fraunhofer.de/en/divisions/division-chemistry/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 carbon dioxide from the atmosphere 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 carbon monoxide tolerant 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 has now realized a methanol reformer with 100 kW power equivalent which can even be scaled up to the MW scale in future. Tests at the reactors are underway. In conjunction with fuel cell technology, 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*

## Liquid Biopsy

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

**THE STATUS:** Different in-house developed microfluidic platforms have been further exploited to isolate circulating tumor cells (CTCs), exosomes, or circulating free (cf)DNA from various samples. While focusing on head and neck cancer patients to isolate CTCs a cooperation is initiated with two German university hospitals to investigate the level of performance in clinical settings.

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 cannot only be used to predict disease outcome but also to suggest potential personalized therapies.

Exosomes are successfully isolated from urine samples and have been analyzed for intracellular biomarkers. A concept of a microfluidic cartridge is under investigation to isolate and analyze cfDNA from blood and plasma samples by an isothermal amplification method. A few of the results have been already published in peer review 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 our platforms, the isolation of other rare cells in body fluids or tissue, exosomes from urine, plasma and blood as well as the detection of cfDNA is subject of further investigations and of additional expert discussions.

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

# PROJECT HIGHLIGHTS

**On the following pages, we have collected a small but fine selection of outstanding projects. Of course, each of our projects basically contributes to the big picture and provides us with the knowledge we need to achieve our goals. True to the words from the editorial, however, we zoom in on our project portfolio and show you the highlights that are particularly representative of our efforts to create a healthy, safe and sustainable world.**

# PROJECT HIGHLIGHTS

On the following pages, we have collected a small but fine selection of outstanding projects. Of course, each of our projects basically contributes to the big picture and provides us with the knowledge we need to achieve our goals. True to the words from the editorial, however, we zoom in on our project portfolio and show you the highlights that are particularly representative of our efforts to create a healthy, safe and sustainable world.

**The more you leave out, the more you highlight what you leave in.**

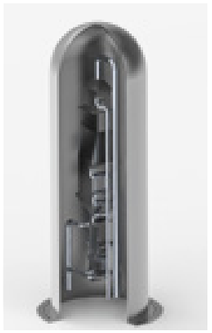
Henry Green

# Development of an innovative reactor concept for the decentralized supply of hydrogen and a supply infrastructure as well as an analytical infrastructure for research in the field of hydrogen supply by ammonia

The AMONPAKTOR project involves the development and construction of an innovative and compact reactor system for the splitting of ammonia for the supply of a conventional hydrogen filling station. For this purpose, a long-term stable and highly active innovative catalyst formulation was developed. The verification of the overall concept is carried out with a container-based, modular demonstration plant for the decentralized supply of hydrogen on the basis of liquid ammonia. The hydrogen produced will be further processed by a pressure swing adsorption system and then converted into electricity in a conventional 50 kW PEM fuel cell. In parallel, it is being investigated whether photocatalytic ammonia splitting has fundamental advantages over thermocatalytic splitting. Economic feasibility and sustainability analyses will be carried out in parallel.

The basis for the hydrogen supply envisaged here are the developments of Fraunhofer IMM in the field of microstructured devices, the processes and plants based on them, and their upscaling for industrial applicability. $CO_2$-free produced (green) ammonia ($NH_3$) can alternatively be used as a regenerative fuel and is easy to store and transport.

The AMMONPOWER project involves the development, construction and commissioning of a supply infrastructure for liquid ammonia under pressure for experimental purposes with an electrical power equivalent of approx. 50 kW. Furthermore, the capacities for the detection of unreacted ammonia in the decomposition product mixture of the ammonia decomposition will be extended by a special gas chromatograph.



*The project AMMONPAKTOR is funded by the Ministerium für Wissenschaft und Gesundheit / RLP, Grant agreement no. 84009390. The project AMMONPOWER is funded by the Ministerium für Wissenschaft und Gesundheit / RLP, Grant agreement no. 724-0032#2022/0003-1501 15402.*

## Fraunhofer IMM tasks

- establishment of a supply infrastructure for liquid ammonia under pressure
- commissioning of new equipment for the analysis of gases and catalyst characterization in ammonia processing
- further development and validation of a stable and highly active innovative catalyst formulation for ammonia splitting
- development and construction of an innovative and compact reactor for the splitting of ammonia
- construction of a demonstrator to verify the feasibility of the overall concept by converting the hydrogen produced into electricity using a conventional PEM fuel cell in the power range of 50 kW
- investigation of new ways of photocatalytic ammonia splitting



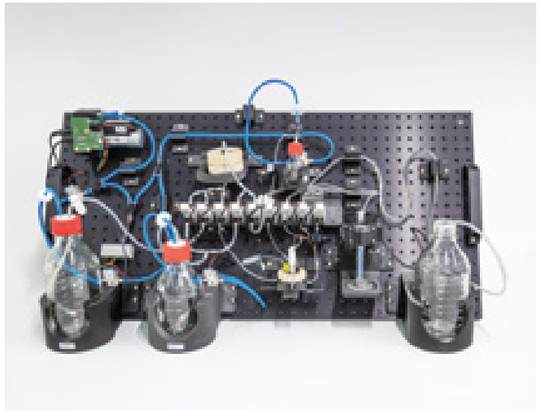


# PCR as a powerful point-of-use bioanalytic tool beyond medical diagnostics

Polymerase Chain Reaction (PCR) is a commonly used and recognized molecular technique for medical diagnostics. The COVID-19 pandemic further boosted the technology. Various PCR-based systems for SARS-CoV-2 testing entered the market, with continuously improved testing speed as well as testing costs. Being matured in medical applications, PCR starts to be accepted as standard in addition to culture methods in many industrial applications, especially when dealing with pathogens in water and food samples.

A key enabler that has significantly advanced PCR in the field of point-of-care (POCT) is microfluidic technology. Automated sample preparation and PCR analytics are available. Today, POCT PCR for diagnostic applications can be considered as a well-developed technology and the industrial learning curve steadily delivers cost-savings and improvements in performance and robustness. The main technology gaps existing so far to apply POCT PCR for industrial applications, e.g. pathogen detection in water industry, are the needs to extract and concentrate the microorganisms from a large volume to microfluidic compatibility at the detection site.

InBaDtec aims to fulfill such technology gaps in order to realize automated preparation of water samples in prior to the use of qPCR analysis. The integrated steps are mainly sample pre-cleaning, microorganism concentration, lysis, mixing, and PCR. An extra optional step to distinguish between live and dead pathogens can also be integrated before the lysis step, to avoid false positive results from dead microorganisms. The InBaDtec project targets two initial applications, one is analyzing the *Legionella* in wastewater, and the other one is analyzing the *Hormoconis resinae* in kerosene.



*The project InBaDtec is funded by Fraunhofer ATTRACT, SAP-no. 40-00440.*

## Fraunhofer IMM tasks

- a fully integrated microorganism concentration module prototype has been built up
- the concentration of bacteria contained in one liter of water to a volume of 200 µl is fully automated in less than ten minutes
- both *E. coli* and *Hormoconis resinae* 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, which reaches the limit of detection < 100 CFU/l

# On-site multi-ion monitoring system for on-line nutrient-laden water control in vertical hydroponic systems to minimize environmental impact

One of the challenges of cultivation in hydroponic systems with closed irrigation is the optimized regulation of nutrients due to the only imprecise information of composition, although many researchers refer to the determination of the concentration of ions in the solution as the key information for optimized operation. Current practice is to determine conductivity, pH, redox potential, and temperature. As a result, the ability to adjust nutrients to the needs of individual crops to avoid undersupply or eutrophication is limited. The nutrient solutions are therefore drained and replaced by the operators at periodic intervals.


*The project AutoNutri is funded by the Bundesministerium für Bildung und Forschung, Grant agreement no. 01DQ22001A.*

The aim of the project is the development of an on-site multi-ion monitoring system for the automated on-line control of fertilizer input in vertical closed-loop hydroponic systems based on feedback-controlled feeding of nutrients. The monitoring system enables effective use of nutrients for optimal plant growth through targeted regeneration of the nutrient solution, thus contributing to a reduction in water pollution due to premature disposal of nutrients dissolved in water into the environment. Nutrient monitoring is based on the direct potentiometric determination of ions using ion-selective sensors. The choice of ions is characteristic of the growth of five selected crops. The sensors are integrated into a microfluidic system, which allows automated sample acquisition and adjustment of the measurement matrix. Prototypes will be made available to end users for beta testing.

## Fraunhofer IMM tasks

The IMM develops the microfluidic based ion monitoring system as a laboratory demonstrator consisting of the modules: sensor technology, microfluidic chip, actuator technology, electronics, and software control.

In the first year of the project,

- system specifications were carried out with the Indian partners
- ion species relevant for the analysis were defined and suitable ion-selective electrodes were developed and tested
- a laboratory setup was implemented in which the ion-selective electrodes could be tested on reference solutions and cross-sensitivities could be analyzed
- the implementation of the laboratory demonstrator into a prototype was discussed with the German partner RM Gerätebau





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

*The project SeedPlus is funded by Fraunhofer PREPARE, SAP-no. 40-04089.*

Facing a growing world population and complex challenges such as climate change and the partial ban on herbicides, high-quality crop yields can only be ensured in the future by optimizing existing and/or developing completely new cultivation methods. Stable high crop yields are essentially the result of undisturbed plant development, especially in the germination phase. Intelligent seed grafting techniques can have a supporting effect here, especially if they compensate for several deficiencies at the same time. In contrast to individual grafting, such multifunctional seed grafting systems are not available on the market.

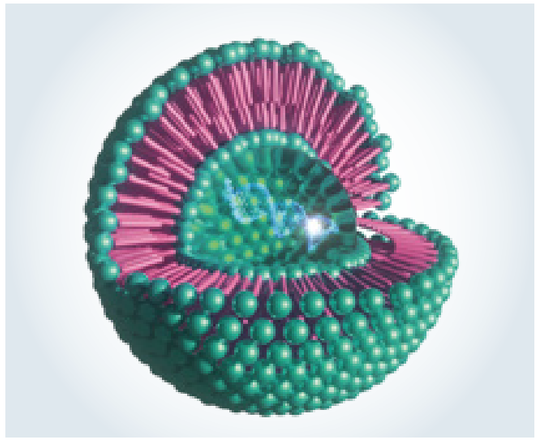
To establish high-yielding crop stands, the germinating seed must be supplied with sufficient water during the emergence phase and protected from site-competing weeds. Based on ecologically safe materials, SeedPlus aims to develop complex seed coatings that have inherent water and crop protection management, enabling effective field emergence even under difficult environmental conditions. This will be achieved by coating the seed with a functional layer for improved water management and a selective barrier to protect the seedling from the applied herbicides. At the same time, the existing regulatory gap in soil protection for such materials will be closed by developing a testing and evaluation strategy. The clear advantage of SeedPlus over previous cultivation methods, with confirmed suitability, lies in the combined and precise application of emergence herbicides and water exclusively in the seed row, which makes the new SeedPlus sowing technique resource-saving, economically lucrative and, above all, more compatible for people and the environment.

## Fraunhofer IMM tasks

Fraunhofer IMM will contribute competencies to the project in the

- development of coating formulation for selective absorption of herbicides
- development of the coating formulation with water retentive property
- characterization of the coating properties
- production and integration of the germination- or growth-promoting additives into the coatings

# RNAuto – Automated production technologies of mRNA-derived vaccines and gene and cell therapeutics



*The project RNAuto is funded by Fraunhofer LEITPROJEKT, SAP-no. 40-02685.*

Globally, the lack of GMP-compliant manufacturing sites and mature production technologies for innovative nanodrugs and cell therapeutics poses major challenges to the healthcare system. The huge potential for mRNA-based vaccines has been particularly evident during the COVID-19 pandemic in the implementation of mRNA manufacturing on an industrial scale. However, barriers have to be broken down to extend the usage of mRNA-based vaccines for further pathogens and boost the application of mRNA-based tools for individual medicine such as for gene and cell therapy. To date, production of cell therapeutics has been manual or only partially automated, resulting in productivity and quality variability as well as extraordinaryly high costs. However, the mRNA-nanocarriers are essential in the future for large-scale industrial production of vaccines and as a critical starting material for gene and cell therapeutics. This will help to provide affordable drugs with which infectious diseases, hereditary diseases, cancer and also cardiovascular diseases can be prevented or treated accessible for a vast majority of patients. Driven by artificial intelligence, automated processes, digitally controlled, in the sense of Industry 4.0 do not yet exist for mRNA nanodrugs, and their establishment requires interdisciplinary collaboration between medicine, biology, and engineering. Automated and digitally supported production technologies are needed to develop mRNA-based drugs quickly, safely and reliably and to produce them according to the high requirements of pharmaceutical manufacturing.

This lighthouse project focuses on developing bioprocessing methods and production technologies for the modular and automated manufacturing of mRNAs, mRNA nanocarriers and mRNA-modified cells that can be transferred to an industrial level. Exemplarily for two use cases, i.e., (1) a vaccine against the West Nile Virus and (2) therapeutics against hematological forms of cancer based on transfected natural killer cells, technological solutions will be established. These include the design and development in the areas of bioreactors, fluid dynamics, quality control and automated data analysis. The overarching goal of the lighthouse project is to create automated and digitally supported production processes of innovative mRNA active ingredients for sustainable and economical healthcare. The entire process chain (from DNA sequence optimization to automated and scalable production of mRNA and mRNA nanocarriers to biological function testing) is to be mapped and optimized with the help of digital twins for an efficient and secure usage. For this purpose, the manual laboratory-scale production of the starting products (mRNA, mRNA-nanocarriers, mRNA-modified cells) will first be optimized and monitored and based on this, automated manufacturing processes will be established. Production technologies required for a GMP-compliant manufacturing of mRNAs as vaccines and mRNA-based gene therapeutics for cancer therapy will be developed up to a clinical scale and conceptionally, towards an industrial scale.

## Fraunhofer IMM tasks

Fraunhofer IMM's skill sets will contribute to the process development of mRNA-based vaccines and therapeutics within this lighthouse project:

- optimization and implementation of (inline) nano- and bioanalytics
- process development for continuous manufacturing of mRNA nanocarriers
- automated, flowcytometric quality monitoring during the production of natural killer cells





# Preparing industrial implementation of an intensified chemical process

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 settings 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.

*The project INCITE is funded by the European Commission, Grant agreement no. 870023.*

These challenges are addressed by applying apparatuses and methods of chemical microprocess technology including flow reactors and membrane separators. Major achievement of Fraunhofer IMM has been to develop a continuous process at lab scale enabling a reduction of process time from several hours to a few minutes and a direct coupling of the two reaction steps. In sum this led to a reduction of reactive intermediate inventory in the process by a factor of 100–200 compared to a batch approach which represents a fundamental gain for process safety.

Now, the focus of Fraunhofer IMM is on contributing to the implementation of this new process within an industrial setting of one of the project partners. The addressed demonstration scale hereby refers to a production of the target molecule in the range of several tens of tons per year. This represents a scale-up factor around 100 compared to lab scale.

Already completed is the central task to further develop Fraunhofer IMM´s reactor technology to that scale. So, corresponding reactors for the first process step and the second process step were realized. The reactors only have reactor volumes in the range of hundreds of $cm^3$ underling the level of reached process intensification once more.

The other core task is the development and realization of a plant surrounding for operation these central reactors considering the later embedment in an overall plant installation at the site of the industrial partner. On one side this means to select or realize required additional equipment like pumps, flow controllers, pressure sensors, back pressure regulators, thermostats, heat exchangers, membrane separators, etc. and to assemble it in a skid. On the other side this means to foresee linkage of the skid to the overall process automatization system at the site of the industrial partner. These works have been completed by Fraunhofer IMM and the developed skid – split to several modules – has been shipped to the industrial partner´s site. Final preparations for the commissioning of the skid and of the overall plant is now the next central running step.

# Acetylation of thin wood veneers and wood fibers by in-situ generated ketene to improve the durability of wood-based materials made from them

Chemical modification of wood is a modern method for improving material properties such as dimensional stability, durability and resistance to wood-destroying fungi and insects. This can open new areas of application for wood, making it more competitive with other materials such as plastic, metal or concrete. The technically most important process for chemical wood modification is acetylation; the most common acetylation reagent is acetic anhydride. However, acetylation with acetic anhydride has two major disadvantages: Process control is complex, requires long reaction times of six to eight hours, and requires large amounts of process water. This makes production very cost intensive. Acetylation produces stoichiometric amounts of acetic acid as a by-product, which results in a strong odor of the finished product. Furthermore, the acetic acid formed leads to degradation of polyoses and certain wood celluloses, as well as discoloration and loss of natural gloss. However, acetylation represents an enormous product upgrade and the demand for such durable and dimensionally stable wood products is increasing. The advantages described are particularly significant for applications in areas with high humidity, such as outdoors, bathrooms and kitchens.

The overall objective of the project is to develop a process for acetylating thin wood veneers and wood fibers using ketene. The entire development chain will be worked out: Starting with the development of the synthesis plants for ketene, to the process development for the modification of wood using ketene, to the sensor-controlled monitoring of the acetylation chambers to meet the required safety criteria. At the end of the project, a 100 liter plant will be available for laboratory-scale production (up to 20 kg of acetylated wood per day). To demonstrate the functionality of the developed process, a seat made of molded plywood as well as a wall element made of MDF for humid or even outdoor use will be produced from the modified woods.

*The project FiVeKet is funded by the Bundesministerium für Ernährung und Landwirtschaft, Grant agreement no. 22000518.*

## Fraunhofer IMM tasks

Fraunhofer IMM will contribute competencies in material development and formulation to the project:

- construction of a process engineering model and design of the main components, including reactor, heat exchanger, temperature-controlled acetylation chamber, disposal module and manually operated control system
- construction/manufacturing of the reactors and checking of the finished plant for its suitability for the acetylation of wood using ketene generated in-situ





# Some more projects we would like to share with you

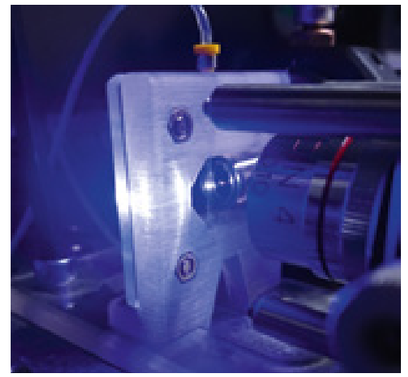
*The project ILLUMINATE is funded by the Bundesministerium für Bildung und Forschung, Grant agreement no. 031B1121.*

## Project ILLUMINATE

Fine chemicals and active pharmaceutical ingredients (APIs) usually base on chiral molecules of high purity. Currently, the synthesis of such compounds is performed in batch mode with homogeneous catalysts resulting in a rather complex and time-consuming process and purification sequence afterwards. The ILLUMINATE project aims at this weak spot and introduces a new technology platform for the next level of fine chemicals production in continuous flow reactors with heterogenized hybridcatalysts. The ILLUMINATE consortium applies the expertise of four Fraunhofer institutes (IGB, IME, IMM, ISC) for establishing the photochemical-assisted biocatalysis as a novel method for the synthesis of chiral compounds under sustainable and process-intensified conditions. This example is the blueprint for future cascade reactions using the synergy of combined catalysis methods with new catalyst material designs and flow chemistry.

## Project DETECTED

For this project, a feedback-regulated nanoparticle reactor is to be realized by combining controllable microfluidic nanoparticle generation from the Institute of Microtechnology (IMT) at the TU Braunschweig with the flowDLS (flow dynamic light scattering) developed at the Fraunhofer IMM in Mainz. The reactor allows for precisely adjusting size, size distribution and shape of the particles and ensures a long-term stable process. The necessary verification of particle properties by measurement and counting has so far only been possible after preparation in separate systems. The flowDLS prototype enables in-line particle measurement during flow. The technology has been further developed so that, in conjunction with a microfluidic particle generation unit, a user-friendly system for nanoparticle production with integrated analytics was created. The envisaged system is to be further developed in this project until it can be used in industrial laboratories.

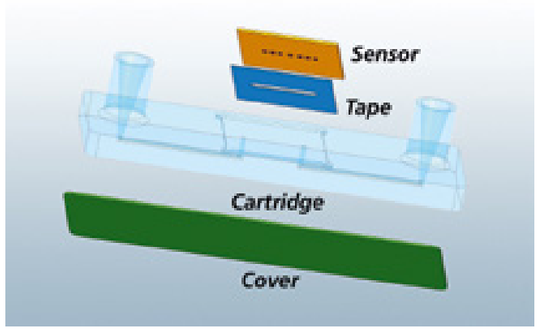


*The project DETECTED is funded by a cooperation of the DFG Deutsche Forschungsgemeinschaft & the Fraunhofer Gesellschaft, SAP-no. 40-03774.*

## Project ORGANOIDICS

The ORGANOIDICS project aims to develop efficient processes for single-cell-based 3D printing of organoids from different cell types. The overall goal is to demonstrate a laboratory-ready 3D bioprinter, that enables the additive production of a “proto-organoid”. This proto-organoid will take the form of a precisely placed pattern of individual cells of different types. Each cell will be ejected from the printer, encapsulated in only a minimum of protective liquid to allow the cells to be printed in very close proximity. This proximity is required to enable the cells to interact and bond into a single multi-cellular unit, serving as a proof-of-concept for the “cell-by-cell” manufacturability of organoids and organ substructures. The planned BioPrinter is intended to provide the different cell types “on-demand” at any given instant, demonstrating that high speed single-cell printing is possible. The BioPrinter will also dispense an extracellular matrix, which the cells require to connect and in which the proto-organoid can remain viable.

*The project ORGANOIDICS is funded by the Ministerium für Wissenschaft und Gesundheit / RLP, Grant agreement no. 724-0032#2022/0006-1501.*



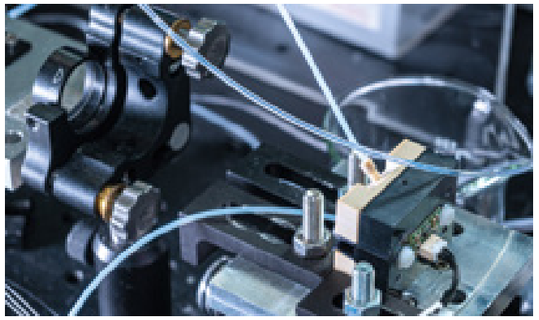

*The project PHOTONGATE is funded by the European Commission, Grant agreement no. 101093042.*

## Project PHOTONGATE

PHOTONGATE aims to develop an adaptable diagnostics solution, comprising of photonic sensor elements inside of microfluidic cartridges and combined with a portable read-out platform. This approach will allow to quantify multiple analytes of similar or different nature (biomolecules, chemicals, metals, bacteria, etc.) in a single test and be able to improve the management of threats to human health or food safety. PHOTONGATE technology relies on a new sensing concept which combines two core technologies: First, bio-chemical molecular gates which will contribute the specificity and increased sensitivity to the system. And second, a photonic technology which will allow signal quantification based on Local Surface Plasmonic Resonance structures (LSPR), working as transducers. PHOTONGATE goals involve a significant progress beyond the State-of-the-Art in multi-sensing systems, achieving a faster and more sensitive detection of multiple targets. A final validation of the PHOTONGATE technology in relevant scenarios of health and food safety will be performed within the project to demonstrate the system capabilities. This approach will therefore provide reliable results in an easier and cheaper way than the current gold standard methods.







*The project IMFLUSS is funded by Fraunhofer SME, SAP-no. 40-03910.*

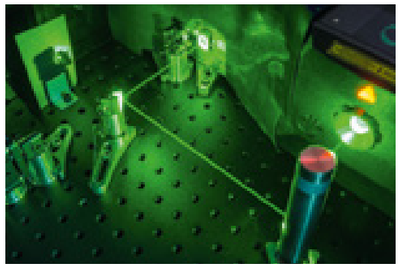
## Project IMFLUSS

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. 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 based on fluorescence lifetime measurements with sub-ns time resolution is being developed. Under the “IMFLUSS” project, important steps towards its realization have been made.

*The project CTCelect is funded by the Bundesministerium für Bildung und Forschung, Grant agreement no. 131A020B.*

## Project CTCelect

The scientists at Fraunhofer IMM have already come a long way in preliminary projects. In cancer research, tumor cells circulating in the blood are seen as an important source of information on the progress of the disease and possible therapeutic approaches. As part of the Ci3 Cluster for Individualized Immune Intervention, a microfluidic flow cytometer with integrated single cell dispenser (CTCelect) was developed that fully automatically isolates tumor cells from a patient’s blood sample. The information on the number of isolated cells may be used for prognostic purposes. The advantage of the CTCelect isolation procedure is that each isolated tumor cell can also be examined for its genetic and molecular biological properties, e.g. by single cell sequencing, which allows the stratification of patients. The so identified tumor type will lead to the best treatment solutions for the individual patient. In future, this also opens up new possibilities for personalized medicine such as immune therapy. The CTCelect workflow for the isolation of single cells from human blood was optimized and tested by using cells from a cancer cell line that were spiked into blood as a model system. In the further course of the project, the aim is to validate and characterize the previously implemented process of enriching and isolating freely circulating tumor cells on real clinical blood samples. It is also of interest to discover the potential of the system to isolate single tumor cells from solid tumors or metastases. In this context we are in contact with other Fraunhofer institutes and clinics for first analyzes. Another focus will be on the investigation and overcoming of major non-technical innovation hurdles.



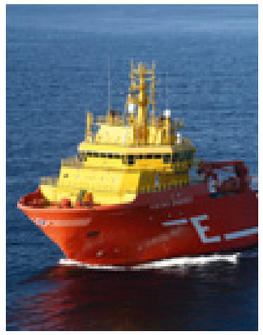
*The project LAMETA is funded by the Bundesministerium für Bildung und Forschung, Grant agreement no. 13N14948.*

## Project LAMETA

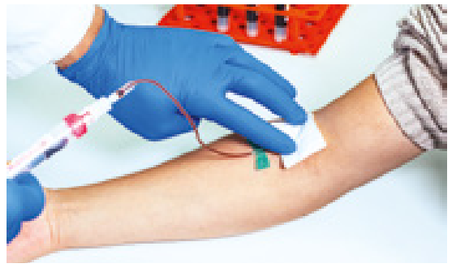
The LAMETA project investigates the generation of 3D metallic nanostructures from the gas phase by means of laser direct writing (LDW) using 2-photon absorption and the limitations of this process. Until now, 3D nanostructures by LDW only can be generated in special photoresists from the liquid or solid phase, which must afterwards be metallized to produce photonically active media with plasmonic properties. The new method reduces the number of process steps required and opens up new applications, e.g. for biosensors, by functionalizing the surface of these free-standing metallic, periodic nanostructures. Germany is a pioneer in the field of laser direct writing of nanostructures, and this role could be significantly enhanced by the project.

## Project ShipFC

Fraunhofer IMM researchers are part of an international consortium aiming to develop ammonia-based fuel cells. When used as fuel for ships with electric engines, ammonia is a high-quality energy carrier and as eco-friendly as hydrogen but easier and safer to handle in transport and storage.The project aims to put the first ship with an ammonia-powered fuel cell out to sea – the Viking Energy, a supply vessel owned by the Norwegian shipping company Eidesvik. Fraunhofer IMM has developed a catalytic converter for the residue of hydrogen and ammonia coming out of the fuel cell, the suitable catalyst for use in the converter and an actual-size prototype for this.



*The project ShipFC is funded by the European Commission, Grant agreement no. 875156.*



*The project RESCUE-SEPS is funded by the Ministerium für Wirtschaft, Verkehr, Landwirtschaft und Weinbau / RLP, Grant agreement no. 7200-007#2020/0001-0801.*

## Project RESCUE-SEPS

RESCUE-SEPS addresses the early and patient-near detection of sepsis. The overall aim of the project is to develop an automated system, including a compact analyzer demonstrator and a disposable microfluidic cartridge, which allows to check for the inflammatory status at the point of need. The approach is based on the use of rapid, microfluidic amplification and detection of circulating cell-free DNA (cfDNA) present in the patient's blood. The automated overall system will enable a rapid diagnosis, treatment and monitoring of septic patients.





## Project OPEN-POCT

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 has been developed, 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 it has been demonstrated that such a system can be equipped with a robot which is able to fulfill sample handling in a fully automated way showing the potential of the platform to be used for mass testing of the population.

*The project OPEN-POCT is funded by the Ministerium für Wissenschaft und Gesundheit / RLP, Grant agreement no. 84009429.*

*The project Batch2Konti is funded by the Ministerium für Wissenschaft und Gesundheit / RLP, Grant agreement no. 724-0035#2021/0012-1501 15402.*

## Project Batch2Konti

Usually, bioprocesses are run in a batch-like procedure, which means that the process is started in a contained bioreactor and runs until the product can be harvested. Continuous processes on the other hand, where the temporal progress is mapped to the spatial dimension along a pipe reactor in a continuous flow, allow for an easier scale-up and a continuous harvesting of the product. To transform the bioprocess from a batch- to a conti-process, a good model of the underlying process dynamics is required. In a bioprocess, this typically involves the measurement of as many important parameters as possible, in particular the viability and cell count of the organism. In the Batch2Konti project, the Fraunhofer IMM setup the production of acetic acid in a bioreactor as an exemplary bioprocess and built a system for the automatic flowcytometric measurement of viability and cell count. The Fraunhofer ITWM modelled the underlying process dynamics and conceptualized a path towards a continuous production of acetic acid in a plug flow reactor.

*The project EPI-CARE is funded by the Bundesministerium für Bildung und Forschung, Grant agreement no. 13GW0593C.*

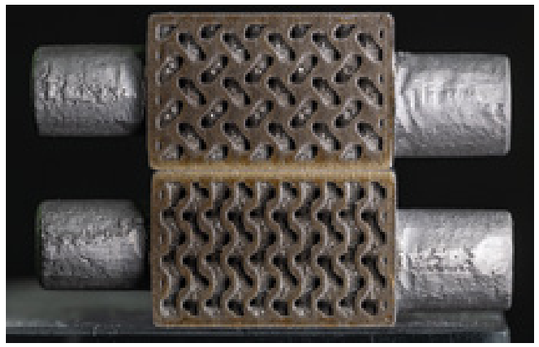
## Project EPI-CARE

EPI-CARE focuses on the development and research of a rapid analysis system for the quantification of circulating cell-free DNA (cfDNA) for the prognosis and clinical management of epidemic infectious diseases. The analysis process, based on isothermal nucleic acid amplification, is fully automated on a disposable microfluidic cartridge and requires no more than a few microliters of blood as test material. This allows a flexible application for future use outside a laboratory environment, for example directly in intensive care units. In its subproject, Fraunhofer IMM addresses the development of the microfluidic analysis cartridge.

## Project METHODIK

The METHODIK project aims to develop a platform of low-cost subsystems or assemblies for a scalable fuel cell platform to produce and market portable or semi-portable energy generators in the power range of 1.5–5 kW. These energy generators use methanol as a sustainable and easily storable and transportable hydrogen carrier.

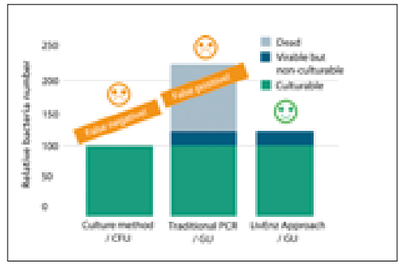
The main objective of this project is to design the major components of the methanol fuel cell in such a way that the subsystems are scalable and have high efficiency, manufacturing costs are reduced, multiple functions can be integrated into one assembly, and system assembly costs are reduced. The reduction in manufacturing costs of the individual components and subsystems is to be achieved by using mass production techniques such as embossing, soldering or optimized additive manufacturing processes. With its high energy efficiency and low manufacturing costs, the envisaged platform should ultimately be superior to diesel generators even in the lower four-digit unit volume range.



*The project METHODIK is funded by the Bundesministerium für Wirtschaft und Klimaschutz, Grant agreement no. 03EN5019D.*








*The project LivEnz is funded by Fraunhofer DISCOVER, SAP-no. 40-02545.*

## Project LivEnz

Monitoring of microbial contamination is of vital importance in many applications, including water quality control and food safety inspection. In most analysis scenarios, relevant microbial contaminations refer not to the total, but only the viable amounts of microorganisms (MOs).

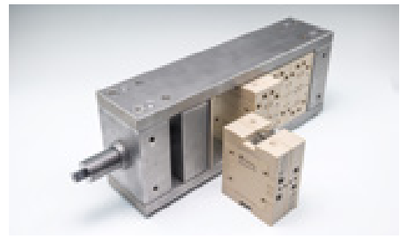
The traditional detection method relies on lab culture, which is time-consuming and has a lack of sensitivity due to microorganisms “sleeping” in the VBNC (viable but non-culturable) state. LivEnz addresses the demand for a fast and quantitative detection method which is only sensitive to living MOs.

The project has validated a novel approach to combine routine PCR technique and a non-toxic pretreatment to detect only the viable microorganisms. The method has been verified with real rainwater and meat samples. This unique pretreatment is able to ensure non false positive results by selectively inhibiting the DNA amplification and detection from dead cells. In addition it avoids non false negative results from living cells as it is non-toxic. The method thus reliably detects the health hazard posed by a sample.

This will enable the discrimination of viable from non-viable MOs and will allow PCR as a fast and sensitive method for a precise detection of microbial contamination directly related to health hazards. Moreover, this 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.

## Project ELMISCREEN

On behalf of the company hte GmbH, Fraunhofer IMM develops and realizes modular electrochemical flow-through cells. These cells will be integrated in the high-throughput screening platform for catalysis research of hte GmbH. The aim is to extend the applicability of the client´s screening platform to new fields of application such as electrocatalysis. This endeavor has to be seen in context of the growing importance of electrochemical processes, e.g. like water electrolysis, driven by energy transition and the search for greener chemical production processes.



### Further information

For more detailed information please check out our website.

# WHAT`S NEXT

**After the project is before the project – work never stands still for us. The following could be the next project highlights – and further milestones on the way to make a sustainable contribution to improving efficient energy supply, food supply and health in the long term.**

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**After the project is before the project – work never stands still for us. The following could be the next project highlights – and further milestones on the way to make a sustainable contribution to improving efficient energy supply, food supply and health in the long term.**

**The best way to predict your future is to create it.**

**Peter Drucker**

# Cluster SPORT

*The SPORT cluster (special lipids and process technologies for optimized RNA therapeutics) is funded by the Bundesministerium für Wirtschaft und Klimaschutz.*

Under a new funding program of the German Federal Ministry for Economic Affairs and Climate Action to improve production capacities as well as research and development of performance lipids and other excipients for mRNA vaccines and other mRNA drugs, a consortium led by BioNTech will receive funding for five years starting in 2023. The consortium includes research groups from Johannes Gutenberg University Mainz (JGU), the University of Leipzig and two Fraunhofer Institutes (IMM Mainz and IZI-BB Potsdam); Lipoid GmbH is another industrial partner.

The funded projects focus on carriers for RNA to enable RNA therapeutics. These carriers ensure sufficient shelf life of the RNA and, after delivery, enable transport in the body and targeted uptake into specific cells. They are crucial for the duration and site of action of mRNA-based drugs.

Fraunhofer IMM will contribute with its expertise in formulation technology and nano-analytics aiming on the development of optimized microtechnology-based formulation modules. These will allow the production of innovative lipid- and polymer-based nanocarrier systems for mRNA at different scales from discovery to production.

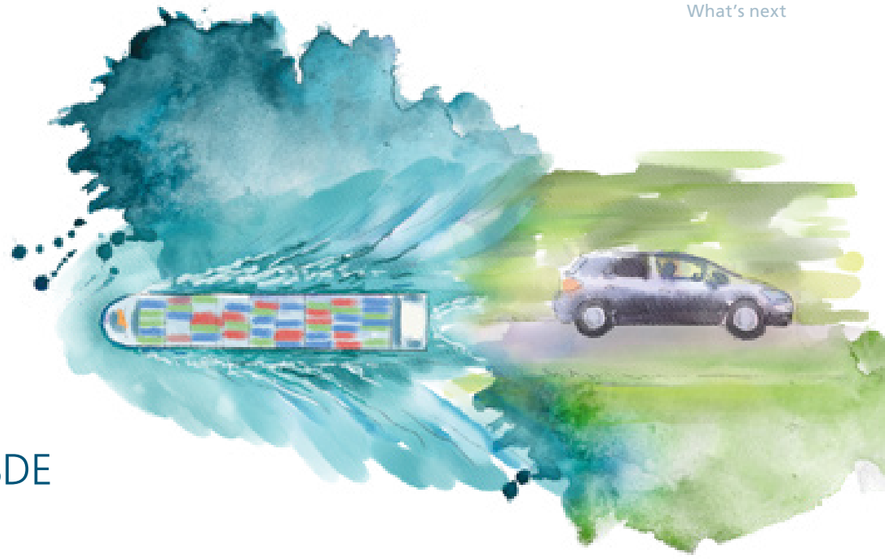
# Project SenseForMask

FFP2 masks, when used correctly, protect the wearer's breathing air from potentially hazardous particles and aerosols. They are indispensable as personal protective equipment, especially during a pandemic. However, filter efficiency decreases over the duration of wear. The filter efficiency is essentially based on the function of the electrostatically charged "meltblown layers" within the mask. The electrostatic charge binds particles and aerosols penetrating through the inner or outer cover layer of the mask which consists of a spunbonded fabric. However, as moisture absorption increases, the electrostatic charge degrades, leading to a reduction in the filter efficiency. The goal of this project is to develop a sensor that monitors the pressure conditions and humidity of the breathing air in the mask to determine the correct fit and maximum wearing time. Based on this information, the user will be warned if the mask is worn incorrectly and before the potentially dangerous filter limits are reached.

*The project SenseForMask is funded by the Bundesministerium für Wirtschaft und Klimaschutz, Grant agreement no. 16PS203802.*







# Project HUMSYSDE

In this project Parker Hannifin's Engine Mobile Filtration EMEA Division (EMFE) and the Fraunhofer Institute for Microengineering and Microsystems IMM are developing and testing new proprietary hollow fibre membrane technology designed for fuel cell humidification applications. Fuel cell technology is key to reduce emissions worldwide. The partners are confident that the hollow fibre membrane technology will be further improved, the service life of the fuel cell humidifiers will be extended, and their efficiency will be increased for the customers.

The partnership is expected to last for up to two years and covers: Efficiency evaluations of existing Parker-designed fuel cell humidifiers, the development and use of a specialized test rig and performance simulations to identify the effects of fibre design parameters on the humidifiers.

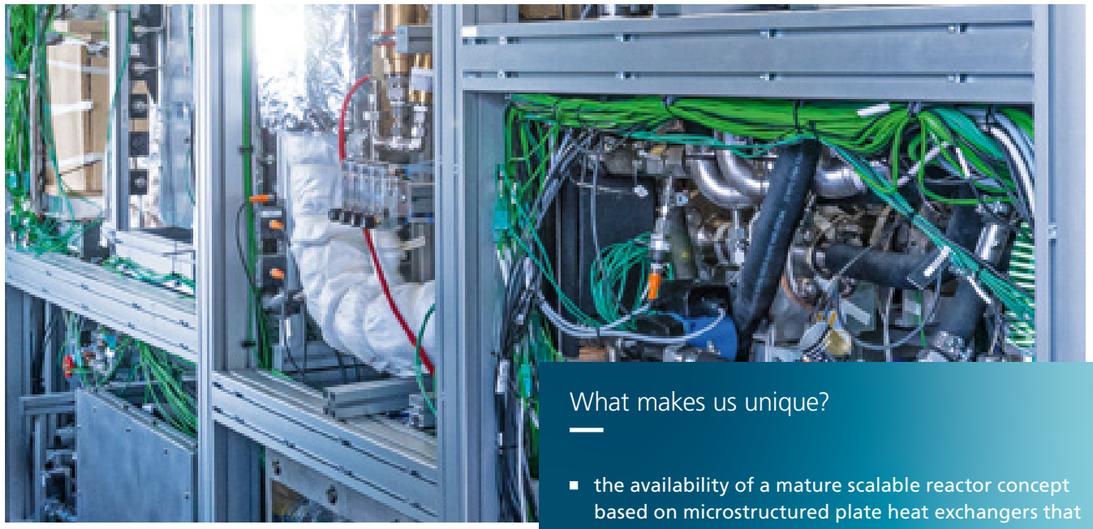
# Project HAVANA

*The project HAVANA is funded by the Bundesministerium für Bildung und Forschung, Grant agreement no. 03ZU1205DC.*

Electrochemistry is considered as future technology for the environmentally friendly production of chemicals. The target of HAVANA is the development of electrochemical pathways to one of the most important classes of substances in the pharmaceutical industry – amines. One access to these is via Hofmann degradation of carboxylic acid amides. However, the halogens like bromine needed for this reaction step are highly corrosive and toxic. In the electrochemical approach, the anodic oxidation of easily handled bromides is an efficient and mild process to avoid using hazardous bromine. Process development will be followed by the transfer of the process into an industrial setting including the scale-up of the electrochemical reactor.

# BUSINESS FIELDS

**Working together on the big picture and yet focusing on specific topics and projects – zooming out and back in – is what our employees in the three divisions ENERGY, CHEMISTRY and DIAGNOSTICS do. We focus on sustainable and efficient energy supply, on green and sustainable chemistry as well as on rapid and personalized diagnostics. With our work we want to make a difference. For people, for you.**



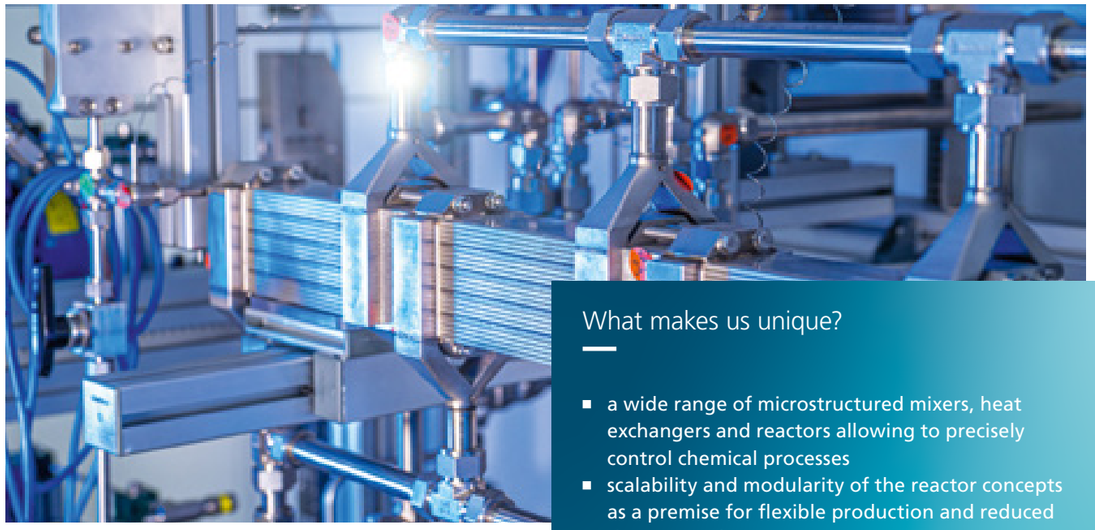
# Energy

## 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

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 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 deep sea 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 reformer reactors, 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.



# Chemistry

## 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 concepts 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 for special reaction classes like electro- and photochemical syntheses, syntheses of reactive intermediates and polymers, nanoparticle synthesis and encapsulation
- special sensor technology

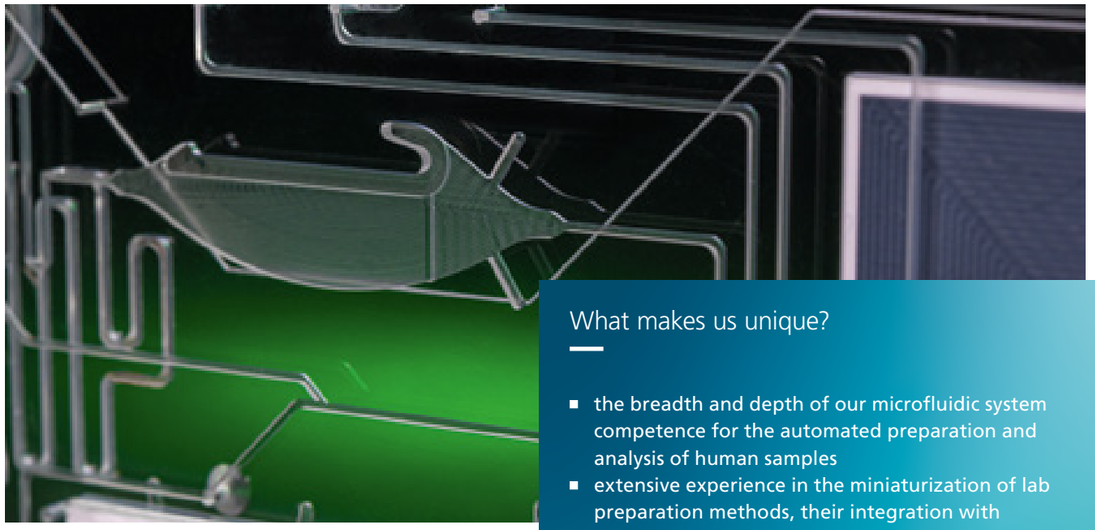
The chemical and pharmaceutical industry need to evolve and adapt themselves to the changing market conditions constantly. These include an increasing commoditization of chemical products, a changing raw material base and climate change directly linked to the context of energy transition. Moreover, society increasingly voices the expectation that production and consumption need to become more resource-saving, environmentally 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 including the realization of reactive intermediates and nanoparticular formulations using in-house technologies. These technologies enable precisely controlled and safe continuous chemical processes with increased resource and energy efficiency as well as tailor-made properties for the target products. They foster decentralized, modular and flexible production concepts e.g. facilitating the adaptation to a raw material base changing towards more renewables. Moreover, regeneratively produced excess electricity can be used to produce valuable chemicals with a 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.

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







# Diagnostics

## 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

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

**Catalysts are used for a variety of purposes: For example, they can make a (chemical) synthesis of active ingredients more efficient and resource-saving, or simplify and accelerate a combustion process. Even though the targets are different, they combine our decades of know-how in microtechnology. And if we zoom out again, the goal that the Catalyst Technology and Sustainable Synthesis Processes Groups pursue with both their purposes is the same: conserving resources and developing sustainable alternative fuels to protect our planet.**

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**»Talent wins games, but teamwork and intelligence win championships.«**

**Michael Jordan**

# Sustainable Chemical Syntheses Group

**The Sustainable Chemical Syntheses Group is taking up green syntheses approaches and combining them with the methods and components of chemical micro process technology and flow chemistry. This is done in an integrated approach of process, reactor and plant development to attain finally economically viable and ecologically sustainable high performance production processes especially for the chemical and pharmaceutical industry.**

Generally, chemical micro process technology and flow chemistry enable an improved control over the process conditions of chemical reactions. This results then e.g. in higher product selectivities and yields, in tailored product qualities, and the opening of novel process windows not feasible with conventional approaches. The transfer to larger scale production is facilitated by modular and scalable reactor concepts.

The focus is on green synthesis approaches such as electrochemistry, photochemistry, biocatalysis and innovative combinations thereof. In the context of the energy and raw materials transition, electrochemical processes pose an advantage, as they run on electricity rather than chemical reagents. They can also actively respond to fluctuations in the power supply. In photochemistry material conversion is initiated by the absorption of light. This is often done close to room temperature and under normal pressure. Photons as reagents and the mild process conditions makes this approach sustainable and environmentally friendly. This is also true for the use of biocatalysts in the syntheses of organic compounds.

## Major projects of the group

- demonstration of the scalability of our electrochemical cells to industry relevant throughput ranges by increasing the number of cell operated in parallel in a joined housing on the example of the Kolbe electrolysis of long chain carboxylic acids delivering alkanes
- development of electrochemical pathways to one of the most important classes of substances in the pharmaceutical industry – amines. One attractive access to these is via carbamates obtained by Hofmann degradation of carboxylic acid amides which can be obtained readily from good available carboxylic acids. However, the halogens like bromine needed for the Hofmann degradation are highly corrosive and toxic, so their use poses a safety risk. In the electrochemical approach, the anodic oxidation of easily handled bromides is an efficient and mild process to avoid using hazardous bromine. Aside the process development, the transfer of the process into an industrial setting requiring amongst others the scale-up of the electrochemical reactor is a key target.
- development of cascade reactions in continuous flow, combining photochemical catalysis with precious metal, organo- or biocatalysis to attain a particularly large synergy for multi-stage syntheses e.g. of chiral fine chemicals. This is accompanied by the development of a modular synthesis platform including specially adapted flow reactors.
- development and realization of modular electrochemical flow-through cells for integration into a high-throughput screening platform for catalysis research

*Receiving funding from*
- *Industry (e.g. project with hte GmbH, Heidelberg, Germany, on the development of electrochemical cells for a screening platform)*
- *Fraunhofer (PREPARE-project Biolight)*
- *Federal Ministry of Education and Research Germany (Illuminate and HAVANA)*

The mind behind:
Dr. Patrick Löb

**2021 – present**
Fraunhofer IMM, Mainz
Deputy Head of Division Chemistry and Head of group "Flow Chemistry" and "Sustainable Chemical Syntheses"

**2018 – 2020**
Fraunhofer IMM, Mainz
Deputy Head of Division Energy and Chemical Technology

**2016 – 2017**
Fraunhofer ICT-IMM, Mainz
Deputy Head of Division Energy and Chemical Technology

**2014 – 2015**
Fraunhofer ICT-IMM, Mainz
Head of the Department Continuous Chemical Engineering

**2008 – 2013**
Institut für Mikrotechnik Mainz GmbH, Mainz
Head of the Mixing and Fine Chemistry Department

**2003 – 2007**
Institut für Mikrotechnik Mainz GmbH, Mainz
Group leader Mixing and Reaction Engineering

**2001 – 2003**
Institut für Mikrotechnik Mainz GmbH, Mainz
Scientist in the area of Chemical Micro Process Engineering

**1997 – 2000**
Ruprecht-Karls-Universität Heidelberg
PhD in Chemistry

**1991 – 1997**
Ruprecht-Karls-Universität Heidelberg
Diploma in Chemistry

# Catalyst Technology Group

**Over the last decade, the Catalyst Technology Group has gathered profound knowledge in the field of energy related applications. The focus is on the hydrogen generation by reforming and by ammonia decomposition and catalytic combustion for both the utilization of off-gas in APUs and the neutralization of compounds being hazardous to the environment. This is complemented by an expertise in hydrogen clean-up reactions with the aim to lower the carbon monoxide concentration in the reformate for fuel cell applications.**

The team has wide experience in developing new catalytic formulations and optimizing existing ones, testing catalysts under application-related conditions, proofing long-term stability over 1,000 h and longer, and characterizing catalytic materials.

Besides catalyst development, deposition of these catalysts onto structured surfaces is a further technological pillar of the group. Proven methods are available for depositing catalysts onto both reactor plates and monolithic structures. With respect to a cost-efficient technique for serial production of plate heat exchanger reactors, the team has developed a method for depositing catalysts onto reactor plates by screen printing.

The existing portfolio of long-term stable catalytic materials of the Catalyst Technology group is available to customers. Furthermore, customers can take advantage from service offered in the fields of catalyst preparation, testing, and deposition.

## Major projects of the group

- optimization of a catalyst for the generation of hydrogen by decomposing ammonia at an operating pressure of 10 bar and a weight hourly space velocity of 200 l/h $g_{catalyst}$
- development of a catalyst for the combustion of a SOFC off-gas containing small amounts of ammonia with the aim to mitigate the formation of NOx and $N_2O$
- improving the activity of a catalyst for methanol reforming at operating temperatures of 200 °C and below
- investigating the reforming of pyrolysis gas and pyrolysis oil
- applying screen printing for the deposition of catalysts onto reactor plates for several larger plate heat exchanger reactors having an electrical power up to 100 $kW_{el}$

*Receiving funding from*
- *Horizon 2020 (ShipFC)*
- *Bundesministerium für Wirtschaft und Energie (Innopire)*
- *Land Rheinland-Pfalz im Rahmen des europäischen Fonds für regionale Entwicklung EFRE REACT-EU (AMMONPAKTOR)*
- *Wehrwissenschaftliches Institut für Werk- und Betriebsstoffe (Pyrolyseöle)*



The mind behind:
Dr. Helmut Pennemann

**2012 – present**
Fraunhofer IMM, Mainz
Head of group Catalyst Technology

**2001 – 2011**
Institut für Mikrotechnik Mainz GmbH, Mainz
Scientist, Project leader

**2000 – 2001**
Reuter Chemische Apparatebau KG, Freiburg
Process development

**1996 – 2000**
Carl von Ossietzky Universität Oldenburg
Prof. Dr. J. Martens
PhD Thesis

**1990 – 1996**
Carl von Ossietzky Universität Oldenburg
Diploma in Chemistry

# 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.**

## Sonja Schmitz

»I have been working in the HR department since 2018, especially in recruiting and HR administration. Recruiting includes, among other things, creating and publishing job advertisements, applicant management, and conducting interviews. In the HR administration tasks such as employee entry and leaving, contract changes, etc., but also advising employees on labor law and collective bargaining issues is a large part of my daily work.

For me, every single working day is different based on the work-together with applicants and employees and I never know what "surprises" are coming my way, but it is exactly this range and variety that makes my job exciting. Working with so many different people and finding solutions together for the respective concerns motivates me every day anew.«





## Janis Stiefel

»As an application scientist in the Infection and Cancer Diagnostics group, I am primarily involved in isolating and analyzing single human cells from biological samples. This includes developing microfluidic processes to automate, speed up and simplify otherwise manual analyses for personalized cancer diagnostics. More recently, I have been managing projects from grant applications and lab testing to project exploitation.

What excites me about this work is that you can see interdisciplinary ideas come to life and that we are always discovering new application fields and translations for our technologies. In applied research, there is a real chance that your own concepts will generate added value for society, which is what drives me personally. Through internship, master thesis, research assistant position, doctorate and now as a scientist, I have been active in this area at the institute for five years and was particularly excited recently by how many Fraunhofer Institutes are facing similar challenges and how easy we can establish inter-institutional collaborations. As a young person in the fast-moving research business, my Fraunhofer education also helps me to sharpen my intuition, to visualize ideas in an understandable way and to take other paths when something doesn't work.«

## Detlef Wehner

»I have now been part of the Fraunhofer family since 2009. When I moved to Mainz to join the Fraunhofer IMM communications team in 2020, I was able to seamlessly continue my previous activities. The focus of my responsibilities lies in the planning and organization of trade fairs and events and the management of the institute's social media channels. I also design new flyers or write a press release from time to time – even though, as a studied historian, it is not always easy for me to read into the scientific content.

But that's exactly what's exciting about my work: exploring new things, being allowed to look beyond my own horizons, and also bringing professional colleagues into contact with potential clientele.«

## Mikayil Ayvaz

»I was the first apprentice in the mechanical workshop and have been working in it for 26 years now. During this time, I have worked on the die-sinking EDM machine, the ultra-precision turning machine, the milling machine and the CNC turning machine.

No matter which machine I work on, the work is always varied and challenging and it is fun to achieve the seemingly impossible. In addition, there is a great working atmosphere between colleagues in the workshop. We are very friendly and respectful to each other and look for solutions together, not for scapegoats. The compatibility of work and family is another plus point.«

## Anne Koch

»I have been at the institute since 1996. Initially, I was involved in the development of components for optical data processing in the former optics department. Since my parental leave, I have been working part-time in the laser laboratory, which now belongs to the "Point-of-Use Technologies" group. Since then, I have mainly been involved in the cutting, ablation, structuring and welding of metals and plastics using various laser systems. What I like most about my job at IMM is the versatility of my tasks, the positive working atmosphere and the good work-life balance.«





## Sisi Li

»It has been less than three years since I joined IMM at the end of 2020 as an Attract group leader. After my Ph.D., I have worked in both academia and industry. Overall, I really enjoy my job content at IMM. I can have direct contact with customers and understand their needs like the product manager in the industry, and also I can convert customer needs into R&D projects and lead my team to realize the R&D tasks like the project leader in academia. This is a very fulfilling process, and of course there will be various challenges at the same time, but this is also the most interesting part of my work.

Before I joined IMM, my work was mainly on the application of microfluidic technology in medical diagnostics. The activity I am currently leading my team to expand is mainly to apply microfluidics technology for bioanalysis beyond medicine. This is a newer application field than traditional medical diagnostics. After we have contacted different customers in the past years, we believe this is a field with increasing demand. How to help them solve their problems and to meet their needs is the direction of my work. The reason why I have the confidence to expand this business field is not only based on my personal experience, but more based on IMM's experience in the field of microfluidics for more than 15 years. This is mainly due to the mature interdisciplinary working environment here, where there are excellent talents from various background, who have been well integrated with each other.«

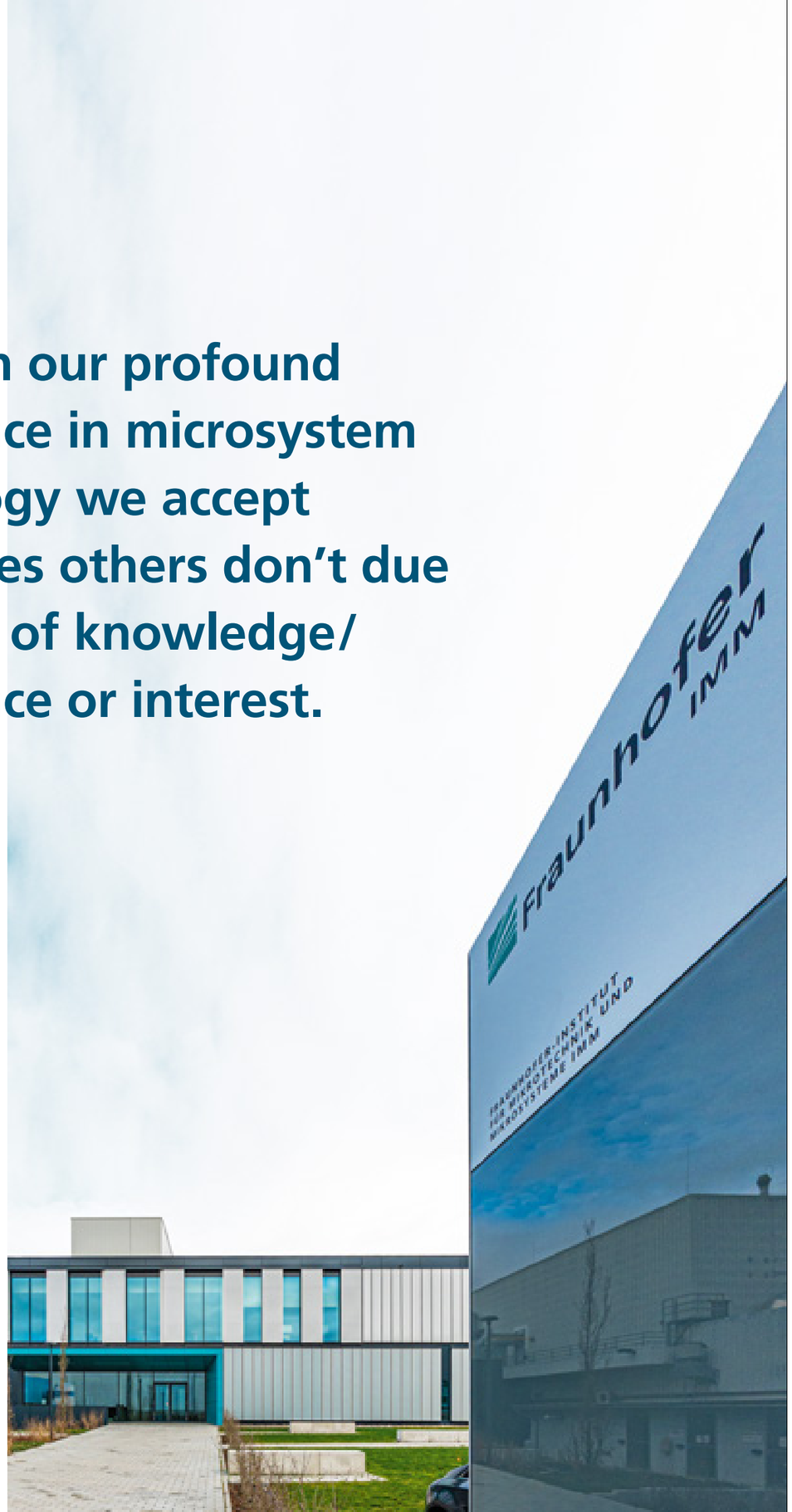
## Dongzhe He

»I work in the "Biological analysis in industrial environment" team for the INBaDTec project, where we are working on developing a device for immediate and effective bacterial detection. In collaboration with other biologists and engineers, I am responsible for the design and manufacture of microfluidic devices and biochips. Applying my engineering expertise to the field of biotechnology has always been my passion. I love to use my knowledge and abilities to create biodiagnostic devices or medical devices that have never existed before, thereby improving people's quality of life. This is what always motivates me to put passion in my work.«

# PROFILE

**After the freestyle comes the duty – here in the shape of background information and a couple of figures.**

**Based on our profound experience in microsystem technology we accept challenges others don’t due to a lack of knowledge/ experience or interest.**




# Fraunhofer Institute for Microengineering and Microsystems

**As leading contract research organization we provide research and development services to our customers and partners from industry, other research organizations and universities for more than 30 years. Transferring requirements into workable and customer friendly solutions we secure a competitive edge and head start in innovation.**

**We create value.**

**With our project work we contribute to the Fraunhofer Strategic Research Fields of Hydrogen Technologies, Resource Efficiency and Climate Technologies, Digital Healthcare and Bioeconomy.**

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 micro-structure 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.

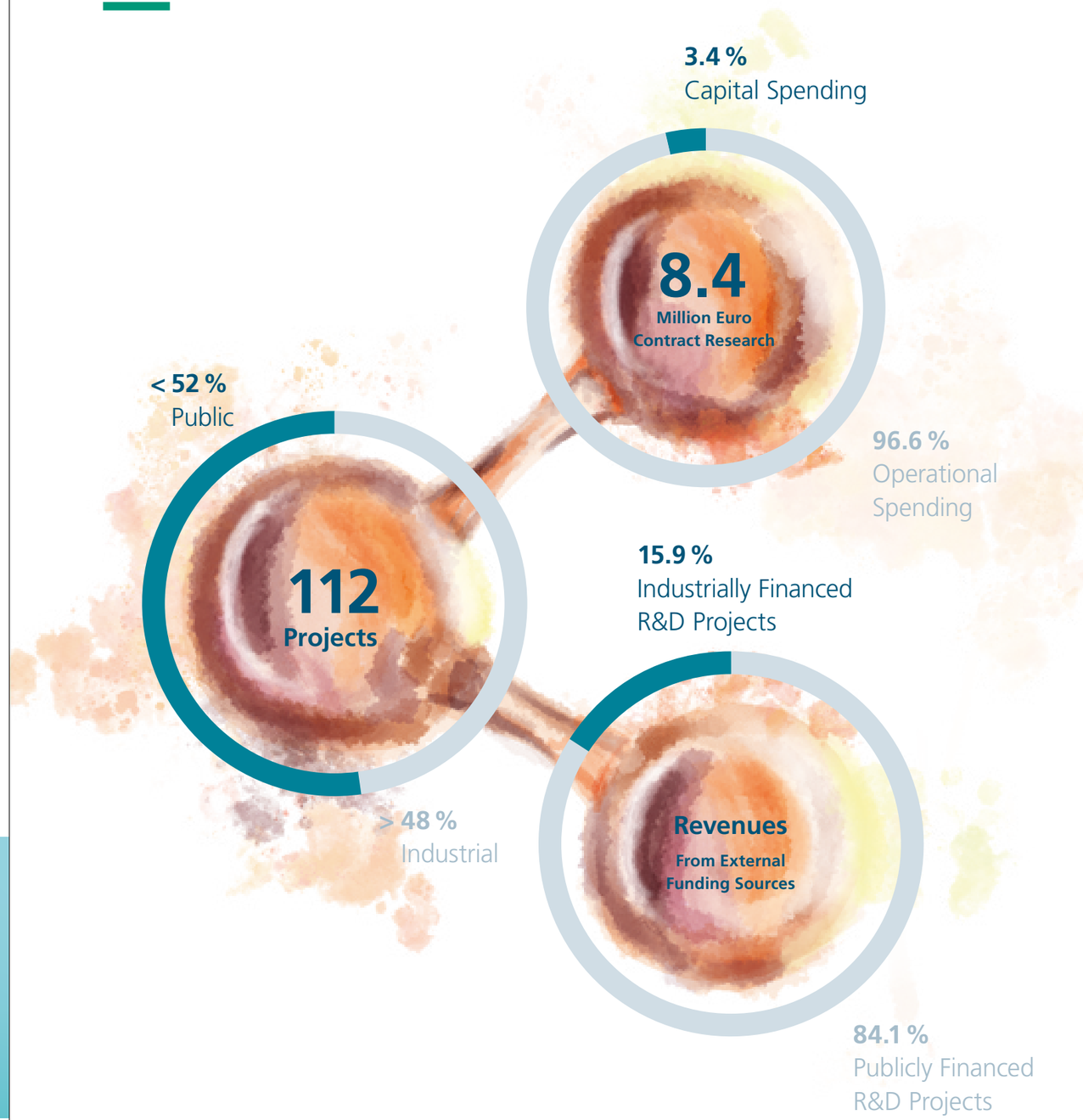
### The value we create

- 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 (2022)



# 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.**

**Regional Network**

**Cooperations and Staff Exchange**

University of Mainz // Max Planck Institute for Polymer Research Mainz // RheinMain University of Applied Sciences

**Student Research Projects and Dissertations**

University of Mainz // University of Applied Sciences Mainz // TU Darmstadt // TU Kaiserslautern // Frankfurt University of Applied Sciences // Kaiserslautern University of Applied Sciences // Bingen University of Applied Sciences // Darmstadt University of Applied Sciences // University of Stuttgart // University of Duisburg-Essen // Karlsruhe Institute of Technology // University of Ulm

**Research Networks**

AMA Verband für Sensorik und Messtechnik e.V. // BMBF Project Partners // TU Eindhoven // Hasselt University // European Technology Platforms // EU Project Partners // BAM Bundesanstalt für Materialforschung und -Prüfung // Dechema // Process-Net // DWV // DGO // Microtec Südwest // N.ERGHY

**Networks**

IVAM // Dual Career Network Rheinmain // Mainz Research Alliance e.V. // Cluster Indiviualized Immuneintervention (CI3) e.V. // INNOMAG // Kompetenznetz Verfahrenstechnik Pro3 e.V. // Transferinitiative Rheinland-Pfalz // Cluster Nanotechnology – Netzwerk NanoAnalytik und -Messtechnik in der Produktion





# Associations and Alliances within Fraunhofer

Fraunhofer **Energy Alliance**

Fraunhofer **Aviation & Space**

Fraunhofer **Nanotechnology FNT**

Fraunhofer **Chemistry Alliance**

Fraunhofer **Hydrogen Network**

Fraunhofer **Group Materials**

# 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. A trailblazer and trendsetter in innovative developments and research excellence, the Fraunhofer-Gesellschaft supports science and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.**

At the Fraunhofer-Gesellschaft, interdisciplinary research teams work with partners from industry and government to turn pioneering ideas into innovative technologies, coordinate and implement system-relevant research projects and strengthen the German and European economies with a commitment to value creation that is based on ethical values. International collaboration with outstanding research partners and companies from around the world brings the Fraunhofer-Gesellschaft into direct contact with the most prominent scientific communities and most influential economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft now operates 76 institutes and research units throughout Germany. Currently around 30,800 employees, predominantly scientists and engineers, work with an annual research budget of about 3.0 billion euros, 2.6 billion euros of which is designated as contract research. Around two thirds of Fraunhofer contract research revenue is generated from industry contracts and publicly funded research projects. The German federal and state governments contribute around another third as base funding, enabling the Fraunhofer institutes to develop solutions now to problems that will drastically impact industry and society in the near future.

The impact of applied research goes far beyond the direct benefits to the client. Fraunhofer institutes strengthen companies' performance and efficiency and promote the acceptance of new technologies within society while also training the future generation of scientists and engineers that the economy so urgently requires.

As a scientific organization, the key to our success is highly motivated employees engaged in cutting-edge research. Fraunhofer therefore offers its researchers the opportunity to undertake independent, creative and, at the same time, targeted work. We help our employees develop professional and personal skills that will enable them to take up positions of responsibility within Fraunhofer itself or at universities, within industry and in society at large. Students involved in projects at Fraunhofer institutes have excellent career prospects on account of the practical vocational training they enjoy and the opportunity to interact with contract partners at an early stage in their career.

The Fraunhofer-Gesellschaft is a recognized non-profit organization named after Joseph von Fraunhofer (1787–1826), an illustrious researcher, inventor and entrepreneur hailing from Munich.

*Figures as of: March 2023*

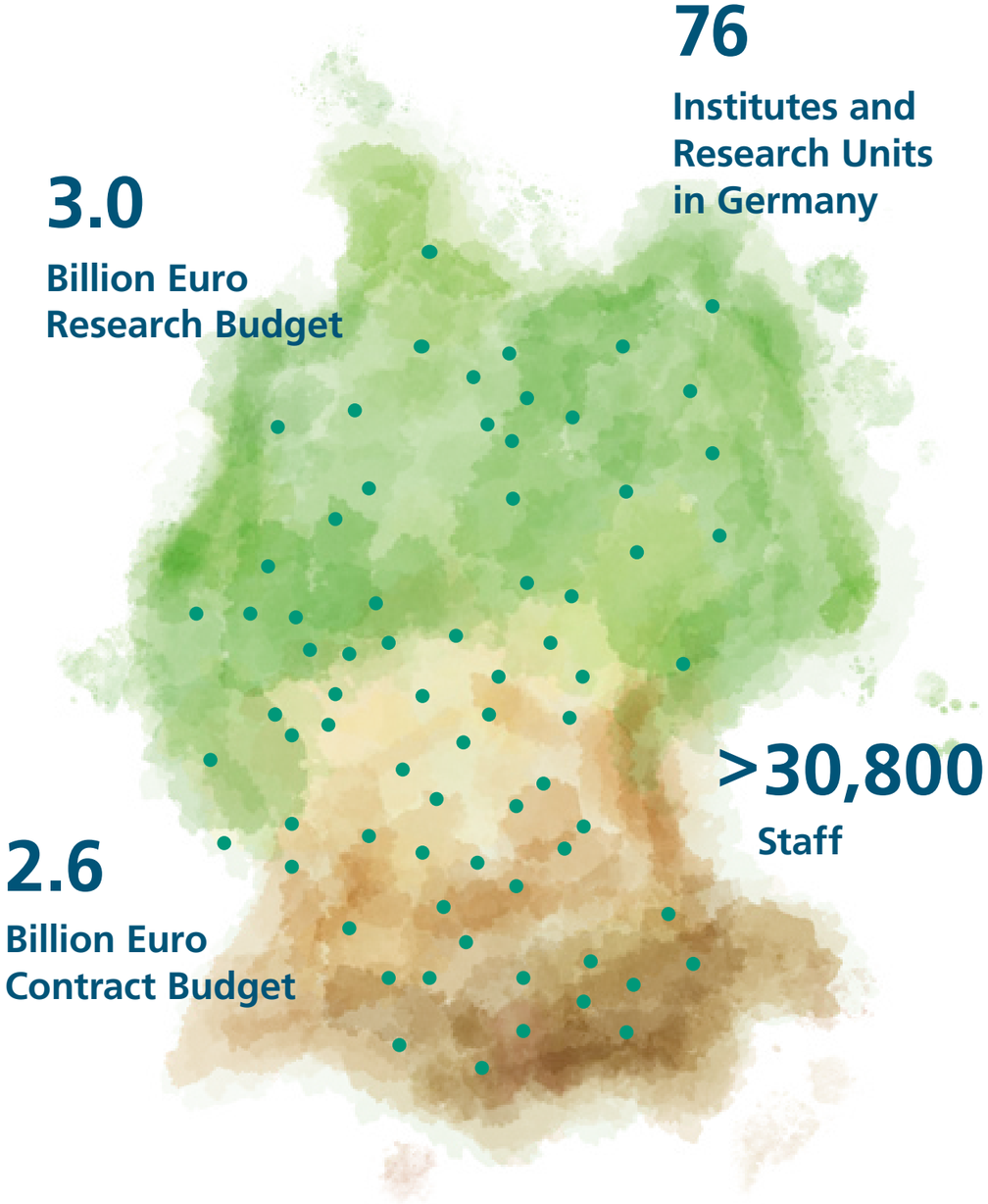




# The Fraunhofer-Gesellschaft in Numbers (2022)

**76**
**Institutes and Research Units in Germany**

**3.0**
**Billion Euro Research Budget**



**>30,800**
**Staff**

**2.6**
**Billion Euro Contract Budget**

# APPENDIX

**And finally, we would like to give you a brief overview of our trade fair and conference participations, as well as our public relations work.**

# Fairs & Events, Conferences & Publications

| Fairs & Events | Date | Type of Event |
|---|---|---|
| Aerospace exhibition ILA 2022 | 22.–26.06.22 | Trade fair, Berlin |
| ACHEMA 2022 | 22.–26.08.2022 | Trade fair, Frankfurt/M. |
| Maritime trade fair SMM 2022 | 06.–09.09.2022 | Trade fair, Hamburg |
| Workshop “SiCellNet – Advanced Single-Cell Tools” | 13.09.2022 | Workshop |
| decarbXpo 2022 | 20.–22.09.2022 | Trade fair, Düsseldorf |
| Online seminar “When PCR as a POCT method for industrial diagnostic applications?” | 05.10.2022 | Virtual presentation |
| Hydrogen Technology Expo Europe 2022 | 19./20.10.2022 | Trade fair, Bremen |
| Hydrogen Online Conference 2022 | 08.11.2022 | Virtual conference |
| Online seminar “Flow photochemistry – a tool for sustainable syntheses that can make a difference” | 09.11.2022 | Virtual presentation |
| COMPAMED 2022 | 14.–17.11.2022 | Trade fair, Düsseldorf |
| 1. Wasserstofftagung Rheinland-Pfalz | 17.11.2022 | Conference, Worms |
| Online seminar “IMM catalyst development: Custom-made catalysts for fuel reforming” | 14.12.2022 | Virtual presentation |
| Bio360 Expo 2023 | 08./09.02.2023 | Conference, Nantes |
| Online seminar “The devil is in the details – Automated isolation of circulating tumor cells from liquid biopsies” | 22.03.2023 | Virtual presentation |
| Hydrogen Online Workshop 2023 | 23.03.2023 | Online Workshop |
| Hannover Messe 2023 | 17.–21.04.2023 | Trade fair, Hannover |
| Online seminar “Small in size, big in importance: What are the advantages of continuous synthesis of nanomaterials and inline/online process analytics?” | 26.04.2023 | Virtual presentation |
| Online seminar “Catalyst development for hydrogen generation by fuel processing” | 24.05.2023 | Virtual presentation |
| Online seminar “Go for green: Microreactors in electrochemical flow synthesis” | 14.06.2023 | Virtual presentation |

**See the list of our publications and conference contributions in 2022:**

*https://s.fhg.de/IMM-Publications-2022*








# Communication Highlights

**This year, we would like to give you a small glimpse behind the scenes of communication again and consequently continue our feature that we started last year.**

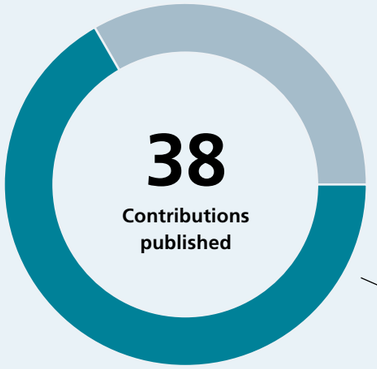
As a small institute, we were able to achieve a good communication reach in 2022 with a fair contribution to the Fraunhofer strategic research fields.

We are also very happy that our internal newsletter, which was launched in 2021, has been so well received and that we were again able to distribute three issues to the colleagues.

However, our absolute heart project was the arrival of three beehives in May, which found their home on the roof of our new building. Our mascot is happy about the buzzing newcomers, the Mainz industrial park about more insect diversity and the employees are looking forward to a tasty honey harvest.

To top it off, here's a little impression of our summer party organized and financed by the employees, where the sun was shining, the food and drinks tasted good and the conversations were fun.

## Press Reach 2022




**11 Mio.**
Contacts reached

**25**
in Fraunhofer Strategic Fields

Bioeconomy, Intelligent Medicine, Quantum Technologies, Ressource Efficiency and Climate Technologies, Hydrogen Technologies





*Internal newsletter*


*Three beehives have been set up on our roof.*

*Summer party at Fraunhofer IMM*

# Advisory Board

**Dr. Peter Dziezok**
Chairman of the Supervisory Board of Fraunhofer IMM
Director R&D Open Innovation
Procter & Gamble Service GmbH

**Dr. Andreas Gerhardt**
Head of Division Supraregional Research Funding
Ministry for Science and Health of Rhineland-Palatinate

**Stefanie Nauel**
Policy Issues for Innovation and Cluster Policy Innovation Funding
Ministry for Economy, Transport Agriculture and Viniculture of the State of Rhineland-Palatinate

**Prof. Dr. Georg Krausch**
President
Johannes Gutenberg University Mainz

**Dr. Ulrich Küsthardt**
Evonik Senior Fellow / former Chief Innovation Officer
EVONIK Industries AG
Managing Partner at Creanova GmbH

**Prof. Dr. Kurt Wagemann**
Executive Director DECHEMA Frankfurt (until 30.06.2021)
DECHEMA Gesellschaft für Chemische Technik
und Biotechnologie e.V.

**Dr. Wolfgang Reich**
Managing Director
C2INNO GmbH
formerly Director Innovation Management BASF SE

**Hans-Mario Dechent**
formerly Director Research and Development Center
Eckes-Granini Group GmbH

**Edgar Mähringer-Kunz**
Managing Director
IMSTec GmbH

**Dr.-Ing. Douglas Khoo**
formerly Head of ISEE Region Germany/Europe
Boehringer Ingelheim Pharma GmbH & Co. KG

**Tobias Brosze**
Managing Board
Mainzer Stadtwerke AG

**Dipl.-Ing. Albert Thomas Haugg**
CEO
Haugg Holding GmbH