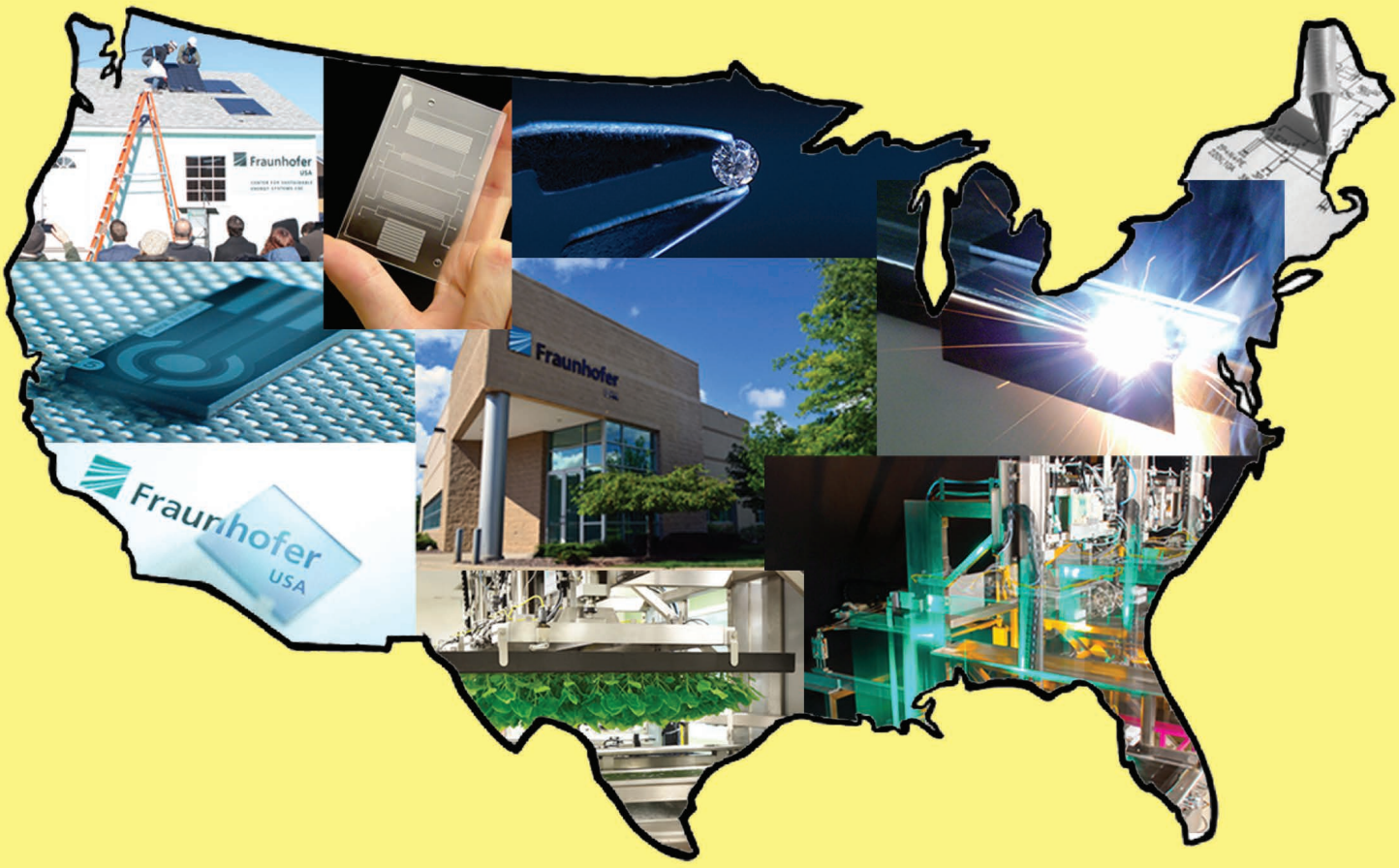
Fraunhofer
USA

R&D PORTFOLIO



Fraunhofer USA

Fraunhofer USA, a subsidiary of Fraunhofer Gesellschaft in Germany, operates seven research centers and two marketing offices. Each research center is affiliated with at least one of the 67 Fraunhofer institutes in Germany and with one major research university in the USA. Fraunhofer USA research centers and Fraunhofer institutes in Germany work together to provide the most versatile cutting edge technologies to a global market. The company offers unique transatlantic business opportunities to close the innovation gap from the lab to the real market and develops and validates scientific applications and technologies for industrial innovation in the USA.

Currently over 220 highly trained and qualified employees at our centers advance the fields of molecular biotechnology, advanced manufacturing, sustainable energy, laser technologies, coatings and diamond technologies, experimental software engineering and energy innovation in the US and strengthen transatlantic collaboration in education, applied research and innovation.

Company
Headquarters: Plymouth, Michigan
Date of incorporation: 09/14/1994
Non-profit 501(c)(3) organization
Website: www.fraunhofer.org

Centers & Offices
Center for Coatings and Diamond Technologies (CCD) - Michigan
Center for Laser Applications (CLA) - Michigan
Center for Sustainable Energy Systems (CSE) - Massachusetts
Center for Manufacturing Innovation (CMI) - Massachusetts
Center for Experimental Software Engineering (CESE) - Maryland
Center for Molecular Biotechnology (CMB) - Delaware
Center for Energy Innovation (CEI) - Connecticut
Digital Media Technologies Office (DMT) - California
Heinrich Hertz Institute Office (HHI) - Washington

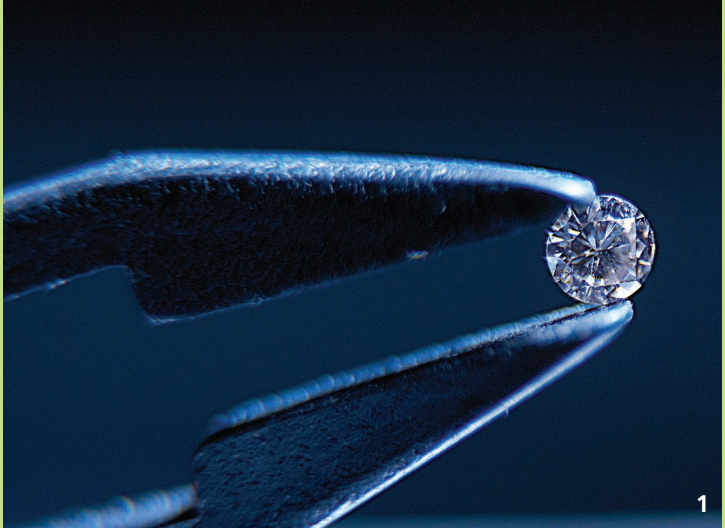
Employees
72 Scientists
54 Engineers
8 Technicians
29 Administration
94 Interns

Highest Education Level
31% Ph.D. degrees
28% Master's degrees
32% Bachelor's degrees
9% Associate's degree or High School Diploma

Customers
300+ active projects in 2015
62% US Industry projects
24% US Government projects
8% International projects
6% Internally funded projects

Revenues
$41 million total contract revenue (2015)

University Partners
Michigan State University
Boston University
University of Maryland
University of Delaware
University of Connecticut



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FRAUNHOFER CENTER FOR COATINGS AND DIAMOND TECHNOLOGIES

We Offer

We offer our competences and resources in diamond and coating technologies to provide our customers with high quality, cost effective and ISO 9001:2008 certified R&D solutions. Projects are performed on dedicated production equipment and range from feasibility studies to solution deployment. We are committed to deliver R&D within agreed specifications, budgets and schedules.

Diamond Materials

- Single-crystalline diamond substrates and crystals
- p- and n-type doped single-crystalline diamond plates
- Electronic grade epitaxial diamond layers
- Coating of microcrystalline diamond films on silicon wafers
- Diamond thermal substrates (thick coatings on wafers up to 4'' (100 mm) diameter)
- Coating of nano- and microcrystalline diamond films on metal substrates (e.g. niobium, molybdenum, tungsten, titanium) and silicon wafers
- Boron-doped diamond electrochemical electrodes, macro- and microarray detectors, 100mm wafer microfabrication capability
- Freestanding diamond foils for X-ray and electron beam windows

Thin Film Coatings

- Superhard and low friction diamond-like carbon coatings (ta-C)
- Doped ta-C:X coatings (ta-C:H, ta-C:F, ta-C:N) for special applications
- Metal nitride wear resistant coatings (TiN, AlTiN, AlTiSiN)
- Aluminum magnesium boride coatings (BAM), AlMgB14)
- Optical thin films for antireflection, antifogging and scratch resistance
- Biocompatible coatings for medical devices
- Magnetic coatings

Industrial Coating Equipment

- Microwave plasma enhanced and hot filament chemical vapor deposition (CVD) reactors for the synthesis of undoped and doped diamond, up to 12'' (300 mm) substrate size
- Physical vapor deposition (PVD) machines to coat parts up to 20" (500 mm) long, plasma sources: cathodic arc, magnetron sputtering, anode layer ion sources

Fabrication Capabilities

- Diamond synthesis and thin film deposition of ceramics (nitrides, oxides, borides), metals, diamond-like carbons and transparent conductive oxides
- Mechanical and chemical-mechanical polishing of diamond
- Lithographic masking (microfabrication)
- Plasma etching (microfabrication)
- Laser micromachining

Analytical Capabilities

- Non-destructive Young's modulus measurement of thin films
- Wear testing (wear volume and coefficient of friction) dry and lubricated
- Surface roughness measurements
- Intrinsic thin film stress measurements
- Contact angle and surface energy measurements
- Cyclic voltammetry for electrochemical analysis
- Raman, FTIR, UV/Vis and photoelectron spectroscopy
- Birefringence measurements
- Electron microscopy

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1 *Brilliant cut single crystal diamond*
© *Fraunhofer USA CCD*

We Offer
Contract research and development, process development, prototyping and consulting services, technical support and pilot production systems.

Laser Cladding and Additive Manufacturing
- Additive manufacturing / rapid prototyping
- Coatings for wear and corrosion protection
- Remanufacturing of worn parts
- ID (internal diameter) cladding
- Induction assisted laser cladding
- Diamond cladding
- Powder and wire fed processing heads
- Process monitoring and control

Laser Welding and Joining
- Laser beam welding
- Remote laser welding
- Laser hybrid welding
- Laser brazing / laser soldering
- Glass welding
- Plastic welding
- Process monitoring and control

Laser Heat Treatment
- Laser hardening & softening
- ID (internal diameter) laser hardening
- Laser assisted forming
- Color marking

Laser Cutting and Drilling
- 5 Axis 3D laser cutting
- Remote laser cutting
- Micromachining / drilling

Laser Sources
Our state-of-the-art laser application facility features the latest and greatest in laser technology with a wide range of lasers from 1 watt to 10 kilowatt output power.

High Power:
- 10 kW Laserline LDF 10.000-60 fiber coupled diode laser
- 4 kW Laserline LDF 4.000-30 fiber coupled diode laser
- 6 kW TRUMPF TruDisk 6001 disc laser
- 5 kW IPG YLR 5000 fiber laser
- 6 kW IPG YLS 6000 fiber laser
- 6 kW Rofin Sinar DC060W slab CO2 laser

Low Power:
- 850 W average power at 1030nm Trumpf TruMicro 7060
- Diode pumped ultrafast solid state laser
- 70 W pulsed 1030 nm Jenoptik IR70 Disc laser
- 17 W @1064nm and 5W @ 355nm pulsed Spectra-Physics HIPPO
- 200 W pulsed 1064 nm LASAG KLS 246 Nd:YAG laser
- 100 W pulsed Rofin SCx10 CO2 laser
- 500 W cw 1070 nm IPG YLR Single mode fiber laser
- 25 W cw 1070 nm JDSU Single mode fiber laser
- 20 W cw 430 nm Fraunhofer Blue diode laser

Additional Equipment
The Center for Laser Applications utilizes additional robotic systems (Kuka) and multiple CNC machines and an onsite metallographic laboratory.

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2 *Laser Welding of Aluminum to Copper*

FRAUNHOFER CENTER FOR SUSTAINABLE ENERGY SYSTEMS

We Offer

A clean energy non-profit applied research and development laboratory.

Building Energy Demand Management

- Understanding of how energy technologies perform in occupied buildings and their impact at scale
- Algorithms and software tool development to optimize building load management and identify energy savings opportunities
- Technology assessment to evaluate the expected energy performance, the current and future economics, market acceptance, and opportunities for emerging energy-saving building technologies, and to characterize the energy consumption of different end uses to inform energy policy deliberators
- Field testing and evaluation of real-world energy-saving performance and market factors of technologies, with focus on thermostats, occupant behavior and HVAC

Advanced Building Enclosures Technologies

- Advanced building enclosures to take advantage of new designs and materials
- Development of innovative building enclosure products
- Performance, quality and durability evaluation of building enclosure systems and components
- Supporting residential and commercial building retrofit markets
- Numerical tool design for thermal and hygrothermal analysis of building materials and architectural components
- Development, demonstration and evaluation of the real-world effectiveness and market adoption of heat storage and dynamic envelope technologies

Photovoltaic Technologies

- Rapid Prototyping of new PV module concepts, and performance and durability assessments
- Solar module performance and durability assessments
- Advanced PV module materials characterization
- Durability and lifetime analysis
- Long-term outdoor testing, PAN file generation
- Failure analysis and materials characterization
- PV module fabrication and prototyping
- Field testing, demonstrations and pilots
- Advanced installation concepts and installation time studies

Distributed Energy Systems

- Exploring how to integrate portfolios of distributed energy resources to match supply and demand in the 21st century electric grid
- System design and integration of PV, energy storage and integrated demand-side management
- Development and deployment of prototype systems for demonstrations
- Support for evaluation of business processes and models
- Field-testing, demonstrations and pilots
- Technology and techno-economic assessment

Techbridge program

- Identifying and de-risking promising technologies to solve industry challenges
- Evaluating and preparing innovative early-stage products for industry and investors by providing technical validation
- "Techbridge Challenges", soliciting the brightest ideas world wide
- Supporting early stage ventures with technical and market expertise
- Assessments of the early venture landscape in energy related fields

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3 *Plug and Play installation*
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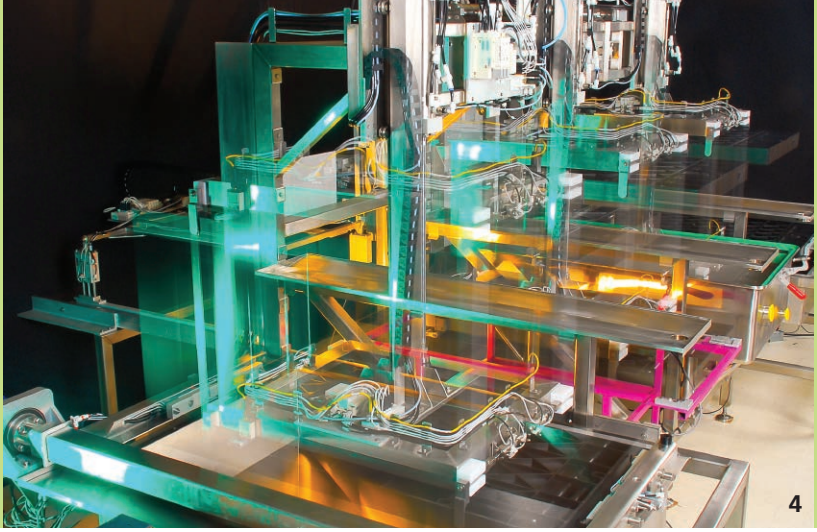

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We Offer

- Custom Automation Systems
- Biomedical Instruments and Devices
- Process Management and Consulting

Custom Automation Systems

Manufacturing automation begins with a thorough understanding of the requirements of the process, followed by a review of commercially available state-of-the-art technologies that may be incorporated. In the cases where there is sufficient commercially available technology to accomplish particular aspects of the process, our engineers and scientists work with our clients to select the best solutions and implement the chosen technologies in a cost effective fashion. We then design new custom automation to create a complete turn-key solution for our clients that meets their efficiency constraints.

We begin by analyzing and, if necessary, modifying the process to make it more conducive to automation. Once the manufacturing process is completely understood, we begin the design and build process, which is comprised of a number of phases and exit points that mitigate risk for our clients:

- Conceptual design
- Feasibility experiments
- Detailed design
- Software and controls development
- Procurement and fabrication
- Assembly and testing

Biomedical Instruments and Devices

One of our core strengths is the application of advanced engineering to biological problems. We combine multiple disciplines in tackling such problems – mechanical design and engineering, electronics and software, biology, chemistry, and assay development – and are trusted by many of the leading pharmaceutical and medical device companies and research collaborators to successfully carry out their project goals. We offer design and engineering services to prototype unique integrated solutions for the biotech and biomedical industries. To meet these needs, we have over 16,000 square feet of fully equipped laboratories including 5 CNC machines which are housed adjacent to our on-site BL1 and BL2 laboratories that are capable of bacterial, viral and mammalian cell culturing. Our major activities are in development of rapid diagnostics, tissue engineering, medical devices, and scientific instruments.

Process Management and Consulting

When faced with production challenges, established companies, startups, and governmental institutions engage CMI to benchmark their current process, and introduce new technologies that will address their challenges. CMI begins the process by reviewing the client's current operation and identifying challenge areas in need of improvement. Technology Scouting is used to bring together possible solutions from internal expertise, university contacts, industry experts, journals, and scientific literature. The ideas are tabulated into technology data sheets showing the evaluation criterion including: field of application, maturity of technology, costs (investment & operational), maintenance/service, and effort of implementation. Final evaluation is performed using a two dimensional technology assessment technique. The down-selected solutions are then proposed for implementation.

Industries

- Aerospace
- Biotech/Biomedical
- Consumer products
- Energy
- Fiber optics/photonics

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4 *Automated Plant-Based Vaccine Production: Delivery of plants for infiltration with a biological vector. ©Fraunhofer USA CMI*

FRAUNHOFER CENTER FOR EXPERIMENTAL SOFTWARE ENGINEERING

We Offer

Innovative, effective, and scalable approaches to software and systems engineering, powerful testing and verification strategies and tools, and state-of-the-art measurement and analysis methods.

Model-Based Development and Testing

- Use analysis tools to automatically extract and visualize software architecture in source code
- Evaluate software architecture to locate policy deviations
- Create software architecture design models to generate test cases, analyze test results, and conduct code inspections
- Reverse-engineer models of code and system traces to identify inefficiencies and liabilities
- Perform architecture-driven verification and validation, analyze systems for architectural risk, and test behaviors of software
- Define and evaluate strategies for automated verification and validation and identify mechanisms that capture and check requirements
- Deploy tools and train personnel on automated testing and verification methodologies, best practices, and secure programming principles

Software Safety and Security Analysis

- Analyze algorithms and architecture to measure impact of upgrading and optimizing systems
- Apply formal modeling methods to evaluate system security and safety
- Detect security attacks in real-time using visualization tools and advanced data analysis techniques
- Evaluate open-source components for integration with commercial systems, with a focus on risk and benefit analyses
- Model reliability data to predict fault-prone binaries in development
- Create risk and safety measurement and management programs to gain insight into safety, security, and reliability
- Quantify software safety risk by analyzing development artifacts
- Collaborate with customers to develop training materials that specify causes

Rapid Prototyping of Mobile and Web Applications

- Design and facilitate user focus groups and empirical experiments to validate customer innovations
- Conduct technology evaluations in cloud, mobile, and other emerging platforms and suggest solutions based upon discovery
- Provide project management support – including agile and scrum methodologies – to mitigate risk, manage cost and schedule, and ensure delivery
- Design, develop, and implement software according to best practices and security, safety, and user experience requirements
- Evaluate and create software engineering approaches and tools to improve software development productivity

Software Engineering Analytics

- Assess software processes and artifacts to ensure sound design and architecture, use of best practices, and regulatory compliance
- Help customers apply best practices (e.g., CMMI, scrum) to systems acquisition and development
- Build process performance baselines and predictive models to manage development projects
- Implement tools and processes for data collection, analysis, and reporting on products and processes
- Oversee design and development to mitigate risks related to requirements creep, software growth, and schedule changes

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5 *Altered stock image ©Fraunhofer USA CESE*

FRAUNHOFER CENTER FOR MOLECULAR BIOTECHNOLOGY

We Offer
- Research and Development
- GMP Manufacturing
- Quality
- Regulatory Support

Research and Development
Our scientific staff, with expertise in diverse fields, combined with our state-of-the-art infrastructure and equipment, well positions the Fraunhofer Center for Molecular Biotechnology to provide R & D services including:

- Proof of concept
- Process development
- Formulation development
- Analytical services
- Preclinical evaluation

GMP Manufacturing
The Center for Molecular Biotechnology GMP bioprocessing facility is a validated Phase I and II compliant pilot plant for the production of biopharmaceuticals using our proprietary plant based expression platform. The GMP manufacturing facility yields gram quantities of target proteins.

The facility consists of class 100,000 fermentation suite and buffer preparation suite, class 10,000 purification suite, and other controlled but non-classified areas. The key processing areas in the pilot plant include:

- Plant growth
- Fermentation
- Infiltration and protein accumulation
- Harvesting
- Protein purification
- Fill and finish

Quality
The Center for Molecular Biotechnology's quality department consists of fully staffed Quality Assurance (QA) and Quality Control (QC) groups with trained personnel experienced in cGMP compliance. QA capabilities include:

- Document control system
- Batch record review
- Product release
- Internal / external auditing
- Review and approval of standard operating procedures (SOP)
- Ongoing validation

Regulatory Support
As a full capability service provider, we also have in house expertise to facilitate regulatory approval for taking potential products to the clinic, including preparing all regulatory packages to obtain the approvals and permits including FDA approval for conducting Phase I and Phase II clinical trials.

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6 *Seeded trays are placed in stainless steel, growth racks in a strictly climate controlled room ©Fraunhofer USA CMB*

FRAUNHOFER CENTER FOR ENERGY INNOVATION

We Offer
Research and development in batteries and energy storage, fuel cells and electrolyzers, microgrid engineering and environmental technology.

Batteries and Energy Storage
R & D activities include new materials, especially metals or ceramics, for anode, cathode and electrolytes of batteries and new methods for joining metals and ceramics, glasses and metal for the purpose of sealing and separation.

Core research areas include:
- Materials development
- Battery cell development
- Energy storage systems development

Fuel Cells and Electrolyzers
R & D activities include the development of new material cell components and catalytic converters, especially burners and reformers.

Core research areas include:
- Fuel cell development
- Stack development
- Systems engineering, prototypes and field trials

Microgrid engineering
Microgrid engineering encompasses the development, integration, and validation of components and subsystems in flexible microgrid architecture for scalable and reliable electrical power distribution and management at the municipal level as well as the community level.

Core research areas include:
- Development of simulation models
- Cooperation with municipalities and cities

Environmental Technology
R & D activities include new materials for gas and liquid separation membranes and catalytic conversion, new manufacturing methods for membranes and catalysts, and procedural aspects of applying membranes and catalytic converters, especially for the purposes of process integration, chemical processing and production of biofuels such as biogas, bioethanol and biomethane.

Core research areas include
- Reduction of CO2 emissions on combustion processes
- Wastewater treatment and water purification
- Biogas generation from biogenic waste for decentralized power generation
- Enhancements in chemical process technology
- Catalytic gas reactions

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7 *Wilhelm plate measurement of the surface tension of molten salts at 600°C.*
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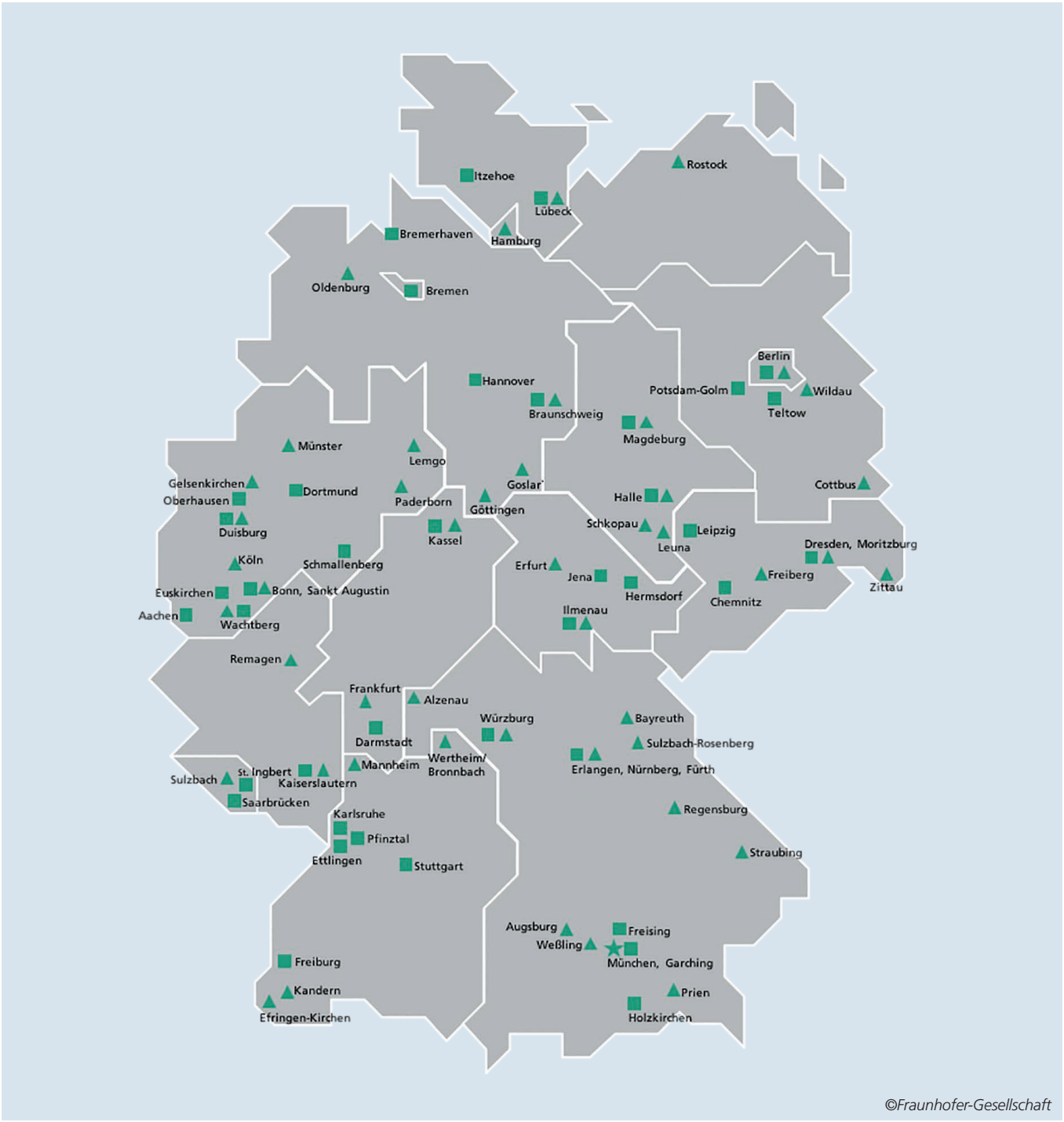

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PARTNER INSTITUTES
FRAUNHOFER GESELLSCHAFT

The Fraunhofer Gesellschaft promotes and conducts applied research in an international context to benefit private and public enterprise and is an asset to society as a whole. The following institutes are directly partnered with Fraunhofer USA centers.

Fraunhofer Institute for Material and Beam Technology (IWS)
Winterbergstr. 28
01277 Dresden, Germany
www.iws.fraunhofer.de
Director: Prof. Dr. Eckhard Beyer
Partner to CCD and CLA

The IWS conducts applied R & D for laser and surface technologies. Core activities include laser welding, cutting, coating, hardening and cleaning; as well as surface and thin film technology, vapor deposition, process monitoring and nano-particle technology.

Fraunhofer Institute for Solar Energy Systems (ISE)
Heidenhofstr. 2
79110 Freiburg, Germany
www.ise.fraunhofer.de
Director: Prof. Dr. Eicke Weber
Partner to CSE

The ISE investigates scientific and technology fundamentals for solar energy applications, develops production technology and prototypes and constructs demonstration systems.

Fraunhofer Institute for Experimental Software Engineering (IESE)
Fraunhofer-Platz 1
67663 Kaiserslautern, Germany
www.iese.fraunhofer.de
Director: Prof. Dr. Peter Liggesmeyer
Partner to CESE

The IESE provides methods and processes for industrial software and systems development based on empirical evidence. IESE employs state of the art scientific knowledge and advanced technologies and tools to its applications.

Fraunhofer Institute for Molecular Biotechnology (IME)
Forckenbeckstrasse 6
52074 Aachen, Germany
www.ime.fraunhofer.de
Director: Prof. Dr. Rainer Fischer
Partner to CMB

The IME conducts R & D in the field of applied life sciences from a molecular level to entire ecosystems in the areas of pharmacy, medicine, chemistry, and agriculture as well as environmental and consumer protection.

Fraunhofer Institute for Production Technology (IPT)
Steinbachstr. 17
52074 Aachen, Germany
www.ipt.fraunhofer.de
Director: Prof. Dr. Fritz Klocke
Partner to CMI

The IPT provides tailor made solutions and immediately actionable results for modern production in the areas of process technology, production machines, mechatronics, production metrology and quality as well as technology management.

Fraunhofer Institute for Ceramic Technologies and Systems (IKTS)
Winterbergstr. 28
01277 Dresden, Germany
www.ikts.fraunhofer.de
Director: Prof. Dr. Alexander Michaelis
Partner to CEI

The IKTS develops modern ceramic high performance materials, customized industrial manufacturing processes and creates prototype components and systems. The center has expertise in diagnostics and testing of materials and processes.

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