

At a glance: Areas of Application and their Technical Potential

Photovoltaics is regarded as one of the most important pillars of the future energy supply. By the end of 2021, 59 GW_p of photovoltaics had been installed in Germany, with about 75 % on roofs and the rest ground mounted. The integration of PV into buildings, vehicles and roads as well as the incorporation into agricultural and water areas and public places in urban centers unlocks vast areas for energy generation with a high economic potential.

Road-Integrated PV
(road and rail, noise protection): 300 GW_p

Building-Integrated PV: 1000 GW_p

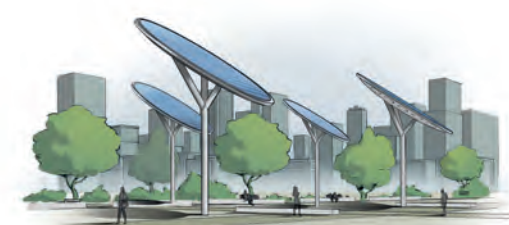
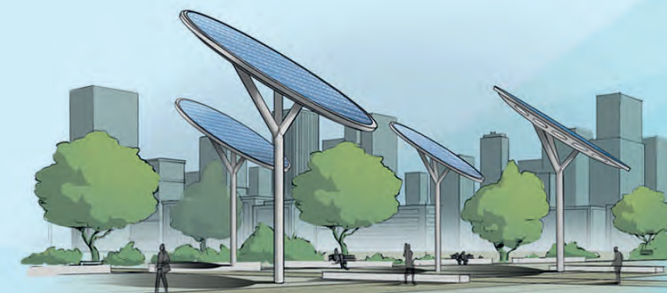
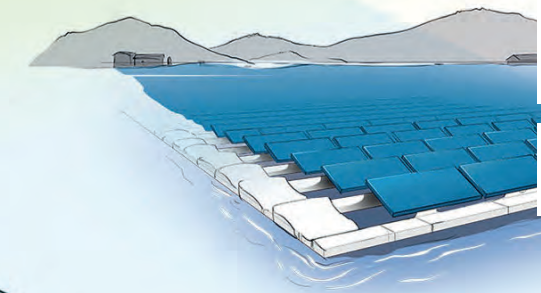
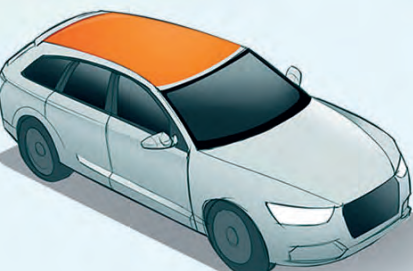
Agrivoltaics: 1700 GW_p

Total Technical Potential:
approx. 3200 GW_p capacity

Urban PV (parking spaces): 59 GW_p

Vehicle-Integrated PV
(car / truck): 55 GW_p

Floating PV: 44 GW_p



Contact

Dr. Harry Wirth
Photovoltaics – Modules and
Power Plants
Phone +49 761 4588-5747
integrated-pv@ise.fraunhofer.de

Fraunhofer Institute for
Solar Energy Systems ISE
Heidenhofstr. 2
79110 Freiburg, Germany

www.ise.fraunhofer.de/en
<https://ise.link/integrated-pv>



Integrated Photovoltaics

Activating Surfaces for the Energy Transition

Cover photo: Integrated PV generates electricity on building facades and roofs, on vehicles, in public places, on noise barriers and road surfaces as well as above agricultural crops and on open water surfaces. © Fraunhofer ISE

Activating Surfaces for the Energy Transition

Integrated Photovoltaics – Active Surfaces Made to Fit

Integrating photovoltaic (PV) technologies into buildings, built-up surfaces or on areas already being used for another purpose unlocks a huge potential for renewable electricity generation. The areas of application are many and varied: Integrated PV fits almost invisibly into building envelopes and vehicle bodies, but also opens up new possibilities along roadways and railways, or as floating PV on flooded open-cast mines, as modules elevated above agricultural land or in urban areas as cover structures in public places.

Potential Space with Synergy Effects

Building-integrated PV and agrivoltaic applications alone offer enough potential space for many 100 GW_p of PV capacity in Germany. Also, integrated PV not only solves land-use conflicts but creates synergies, e.g. increased driving range; an on-site building power supply; noise protection on roads and railways; better protection against hail storms, drought and frost damage for agriculture; and reduced material consumption in buildings and vehicles. Integrated PV can thus make a significant contribution to achieving the target of a 80 % share of renewable electricity by 2030, while making the energy transition a positive experience at the same time.

At Fraunhofer ISE, we develop innovative solutions for the following application areas:

- Building-Integrated PV
- Agrivoltaics
- Vehicle-Integrated PV
- Road-Integrated PV
- Floating PV
- Urban PV

Invisible, highly efficient solar cells in a car roof.

© Fraunhofer ISE



Highly Efficient Cell and Module Technologies

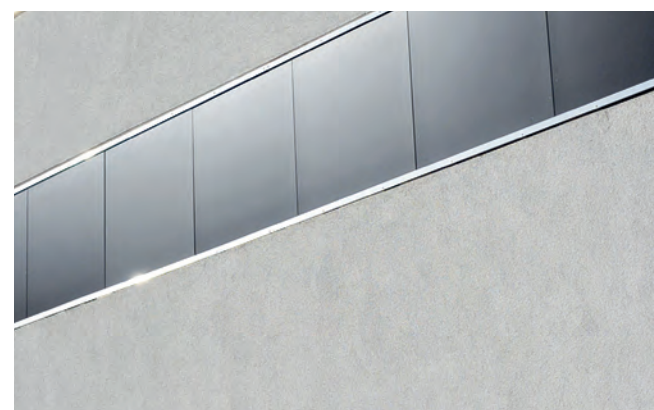
Maximum energy yield within a limited space is a requirement which especially applies to vehicle-integrated PV modules. In addition, passenger cars and building-integrated PV applications place high aesthetic demands on integrated PV. For this purpose, we develop highly efficient silicon solar cells which can be configured flexibly in a PV module featuring filigree metallization and cell interconnections in shingle technology to create attractive vehicle bodies or building envelopes. Our in-house developed MorphoColor® coating delivers a choice of brilliant colors with only a slight efficiency loss of 7 % relative. Our III-V semiconductor cell technology achieves efficiencies of over 35 % and has so far been used primarily in the aerospace industry.

Application-Optimized Module Designs

Integrated PV requires individual solutions in order to meet multi-functional and aesthetic requirements. We support our partners in the development of special module designs and the selection of suitable materials. Shingle interconnections with conductive adhesives, for example, allow the realization of PV modules with the highest efficiency levels, curved surfaces and nearly invisible circuitry. To achieve especially low weight per area, we are exploring glass-free structures for use in lightweight construction applications in commercial vehicles or for roofs with low load-bearing capacity. Thin, lightweight III-V solar cells and foil-based organic solar modules can be integrated particularly well into the curved wings of electrically powered aircrafts. Organic solar modules allow for partial transparency and spectrally selective transmission, e.g. in photovoltaic active window surfaces.

Black PV modules with a matt surface integrated in a building at Fraunhofer ISE.

© Fraunhofer ISE



Research facility for agrivoltaic orcharding in midwestern Germany. © Fraunhofer ISE



Noise barrier with integrated modules. © KOHLHAUER GmbH

Characterization and Testing

In CaLab PV Cells and CaLab PV Modules, our accredited calibration laboratories, we precisely determine the performance data of solar cells and modules under various operating conditions, thus creating the basis for yield simulations. We test the reliability of innovative module designs based on new materials in our accredited TestLab PV Modules and prepare them for product certification. Depending on the application, integrated modules are subject to increased stress levels; for example, in noise protection structures on roadways or in vehicle integration. We analyze specific loads on site and transfer them into equivalent accelerated tests in the lab.

Precise Yield Analysis

Integrated photovoltaics presents special demands on the precise determination of the yield. With physically exact models based on ray tracing and high-quality weather data, we can optimize the dual land use of agrivoltaic systems as well as the performance of building-integrated PV even in partially shaded areas. Furthermore, we simulate energy yields from bifacial modules as well as route-dependent yields in mobile applications. All of our yield models are validated by monitoring data. Based on our cost and yield models, we offer our customers a comprehensive analysis on the profitability and cost of electricity generation.

Flexible, Fully-Automated Production and Digital Construction Processes

A large variety of PV modules is required for building integration applications, some of them in small quantities. Different structures, formats, colors and designs can be used in a single building project. We support our customers in the development of flexible, fully automated production lines for the cost-effective manufacture of individual, small series production. This includes the data flow from planning to production (Computer-Integrated Manufacturing, CIM) as well as the digitalization of construction processes (Building Information Modeling, BIM).

System Development

The integration of photovoltaics is often accompanied by an adaptation and optimization of the entire electrical system. Different orientations and shading effects on the building envelope must be compensated. The vehicle integration of photovoltaic modules requires intelligent battery management systems as well as compact and robust DC/DC converters. We develop integrated solutions for our customers, from system planning up to software solutions and power electronic converters.

Our R&D Services

- highly efficient PV technologies
- application-optimized cell and module designs
- MorphoColor® colored coatings
- sampling in full format on industrial equipment
- module characterization and testing in accredited laboratories
- yield simulation and monitoring
- production lines and digital processes
- power electronics and system integration
- analyses for potential, costs and profitability