



1 *Integrated photovoltaic opens up large area potentials for the generation of solar energy.*

## INTEGRATED PHOTOVOLTAICS – SURFACES BECOME ACTIVE

Integrated photovoltaics merges with the shell of buildings, traffic routes and vehicles. It uses land together with agriculture or covers water surfaces in flooded open-cast mines. The integration of PV opens up huge potentials. Building integrated photovoltaics (BIPV) together with agrophotovoltaics (APV) already could provide several 100 GW of solar power in Germany. Instead of conflicts of use, synergies occur, such as longer ranges for electric vehicles, local power supply for buildings or noise protection on roads and railways.

At Fraunhofer ISE, we are developing new applications in the following areas:

- Building Integrated PV (BIPV)
- Agrophotovoltaics (APV)
- Vehicle Integrated PV (VIPV)
- Road Integrated PV (RIPV)
- Floating PV (FPV)

### Highly Efficient Technologies

Particularly vehicle-integrated PV modules must generate maximum yields on a limited

area. For cars, high aesthetic standards have to be met at the same time. We develop highly efficient, flexibly configurable silicon solar cells with filigree metallization and cell connection in shingles technology for appealing vehicle or building envelopes. Our Morpho coating delivers brilliant colors with low yield loss of around 7% relative.

Our cell technology based on III-V-semiconductors achieves efficiencies of more than 35% and is being used primarily in the aerospace industry.

### Customized Module Designs

Many integrated applications require module designs that meet multifunctional and aesthetic requirements. We support our partners in the development of special designs and the selection of qualified materials. Highest efficiencies, curved surfaces and largely invisible module circuits can be achieved with conductively glued shingle connections. We are researching glass-free laminates in order to achieve a particularly

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low weight per unit area for lightweight construction applications in commercial vehicles or for low-load-bearing roofs.

Thin, lightweight III-V solar cells and film-based organic solar modules are particularly well integrated into the curved wings of electrically powered aircraft. III-V-solar cells have proven their value due to their high radiation stability in space travel. Organic solar modules enable partial transparency and spectrally selective transmission, e.g. in photovoltaically active window surfaces.

#### Characterization and Testing

In our accredited calibration labs CalLab PV Cells and PV Modules we determine the precise performance data of the solar cells and modules under different operating conditions and thus create the basis for yield simulations. We test the reliability of innovative module designs based on new materials in our accredited testing laboratory and prepare the product certification. Depending on the application, integrated modules are also exposed to increased loads, for example in noise protection on roads or vehicle integration. We analyze specific loads and transfer the results into equivalent accelerated laboratory tests.

#### Precise Yield Analysis

Integrated photovoltaics presents special challenges in the precise forecast of its yield potential. With physically exact models based on ray tracing and high-quality weather data, we can optimize the combined land use in agrophotovoltaic applications and the performance of building

integrated PV (BIPV) in partially shaded operation. Bifacial yields can be simulated as well as route-dependent yields in mobile applications. Our revenue models are validated by monitoring. Based on cost and revenue models, we offer comprehensive analyzes of cost-effectiveness and electricity generation costs.

#### Fully Automated, Flexible Production and Digital Building Processes

For building integration, a variety of module variants is required, sometimes in small quantities. In a single construction project, different structures, formats, colors and designs can be used. We support our customers in the development of flexible, fully automated production lines for the cost-effective production of individual small batches. This includes data flow from planning to production (Computer-Integrated Manufacturing, CIM). Planning processes are streamlined and simplified through the digitization of Building Information Modeling (BIM).

#### System Development

The integration of photovoltaics often involves adaptation and optimization of the entire electrical system. In the building envelope different orientations and shading effects have to be compensated. Vehicle integration of photovoltaic modules requires intelligent battery management systems as well as compact and robust DC converters. We develop comprehensive solutions for our customers, from system planning to software solutions and power electronic converters.

- 1 *Curved vehicle roof with integrated PV shingle cells and Morpho color coating.*
- 2 *The agrophotovoltaic system in Heggelbach, Germany enables double harvesting.*
- 3 *Building-integrated PV modules with a matt surface at a Fraunhofer ISE laboratory.*

#### R & D Services

- highly efficient PV technologies
- application-optimized cell and module designs
- morpho-color 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
- potential, cost and economic analysis