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Opinion Article

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Thermophotovoltaics: An Established Idea Entering a New Phase

At temperatures of several hundred degrees Celsius and above, materials emit substantial energy as infrared radiation, with the intensity increasing rapidly as the temperature rises. Thermophotovoltaics (TPV) captures this radiation and converts it directly into electricity using semiconductor cells. The principle resembles solar photovoltaics, but TPV cells are tailored to heat sources such as cooling steel or clinker at around 1,400-1,600 °C and thermal-storage media operating from about 1,200 °C to above 2,400 °C. Narrow-bandgap III-V semiconductors such as InGaAs and GaSb are commonly used to convert this infrared light. With no turbine or working fluid, TPV offers silent, modular heat-to-electricity conversion without moving parts.

TPV is not a new concept. Radioisotope-based TPV systems have provided long-duration power in space and remote applications, while III-V photovoltaics generally have accumulated decades of operational experience under demanding space conditions.



At Fraunhofer ISE, we draw directly on our long-standing work in both space photovoltaics and terrestrial concentrator photovoltaics, particularly in dense-array packaging, operation at high power densities, cooling and reliability. This experience provides a strong technical foundation for TPV receiver development.

Recent research has renewed interest in TPV by demonstrating conversion efficiencies above 40%. Achieving such performance requires both high-quality TPV cells and effective photon management. Integrated back reflectors return unusable sub-bandgap photons to the emitter rather than allowing them to be absorbed as heat in the cell. Spectrally selective emitters or metasurfaces can further tailor the radiation reaching the converter and benefit the overall system.



Long-duration energy storage and industrial waste-heat recovery are two prominent application areas. In a thermal battery, surplus electricity is stored as heat in an inexpensive medium, such as molten silicon or carbon blocks, and later recovered using TPV cells. Such low-cost, scalable thermal storage could be particularly advantageous for discharge periods of many hours or days. In high-temperature industrial processes, TPV can convert part of the otherwise unused thermal radiation into electricity. Because this waste heat comes essentially for free, power density, receiver cost, durability and ease of integration are important alongside conversion efficiency.

Fraunhofer ISE offers unique expertise that combines III-V epitaxy, complete cell processing and module assembly under one roof. This integrated capability allows us to address the tightly coupled challenges of practical TPV systems from absorber material to receiver.

High-quality low-bandgap epitaxy is required to convert the infrared spectrum efficiently. Releasing thin-film devices from precious InP growth substrates enables substrate reuse, a decisive cost lever. Highly reflective back mirrors return sub-bandgap photons to the emitter, but must be integrated without compromising electrical performance. Large-area thin-film cells are mechanically fragile, making handling, dicing and interconnection critical yield challenges. Finally, a dense-array receiver must simultaneously provide electrical interconnection, efficient optical coupling, active cooling and mechanical stability within a compact package, with trade-offs between all four functions.



TPV has demonstrated compelling cell-level performance in the laboratory and is now moving toward larger-scale deployment through several initiatives worldwide. Progress toward broader implementation will require advances on several fronts. High-efficiency cell concepts must transition from laboratory fabrication to scalable, reproducible manufacturing while reducing TPV cell costs.

The long-term stability of cells and the back reflector under sustained high radiative flux and operating temperature must be established. Efficient operation also depends on effective cooling, while the transition from individual cells to large, reliable receiver arrays introduces coupled optical, electrical, thermal and manufacturing challenges. Its suitability will vary by application, depending on how benefits such as efficiency, high power density, modularity and solid-state operation compare with cost and integration requirements.

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The INFERNO project investigates industrial waste-heat recovery as one such case by integrating our TPV cell and module technology into a hybrid TPV-thermoelectric system developed jointly by the project partners and coupled to a metasurface-based collector. Testing in the laboratory and pilot demonstrators will assess performance, durability and integration under relevant operating conditions. This system-level evidence will advance TPV toward practical deployment and establish robust pathways for its use in industrial waste-heat recovery.



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Dr. Helmers is an expert in photovoltaics. He studied physics and philosophy in Oldenburg, Germany, and Lund, Sweden, earning a Ph.D. from the University of Oldenburg. He joined Fraunhofer ISE in 2008 and founded a business area on optical power transfer in 2013. Since 2019, he co-heads the III-V Photovoltaics and Concentrator Technology department. His research focuses on high-efficiency designs for III-V solar cells, photonic power converters and TPV cells, multi-junction architectures, micro-CPV and power-by-light technology. In 2021, a team led by Dr. Helmers demonstrated a record breaking photovoltaic conversion efficiency of 68.9% for 858 nm monochromatic light.

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