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# Breaking Free of the Battery Cage:
# Manufacturing Light Energy Harvesting at Scale

WHITE PAPER 2026

Version 1.1
January 2026

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As the Internet of Things (IoT) continues to expand its reach into nearly every industry, the need for energy efficient devices at the edge increases as well. The sheer number of devices to be deployed in applications like smart buildings, asset tracking networks, and wireless consumer devices such as remote controls drives the necessity for an alternative to wired- and battery-based architectures. Simply put, OEMs need a sustainable energy-generating technology ready for mass production capable of reducing our dependency on batteries in high-volume applications.

This whitepaper will explore Organic Photovoltaic (OPV) light energy harvesting technology, a compelling energy generation solution for many low-power applications. Key topics to be covered include the way OPV generates energy and reduces the need for battery-based storage, how to assess a device's actual energy need to optimize energy generation, and leveraging agile prototyping to quickly integrate OPV light energy harvesting into your design for mass production.

# Light Energy Harvesting for Low Power Applications

Many low power applications need to be wire free to simplify placement and installation. They use batteries to store enough power to operate for months or years. When batteries run out, a maintenance call must be made to replace them. This makes battery replacement a major ongoing maintenance cost.

For example, Figure 1 estimates the total cost of ownership for a typical Enterprise with 25,000 sensors across locations. For a battery-powered approach, maintenance is estimated at 5 million euro. In addition, the company will have to dispose of more than 250,000 batteries over the lifetime of the IoT system. An energy harvesting technology like OPV lowers maintenance to 3 million euro by reducing the expense required for battery replacement, a savings of up to 40%. Reducing or eliminating the disposal of so many batteries also significantly impacts customer perception of a company's commitment to sustainability.

**TCO comparison**

Battery powered vs. OPV for a smart building IoT solution

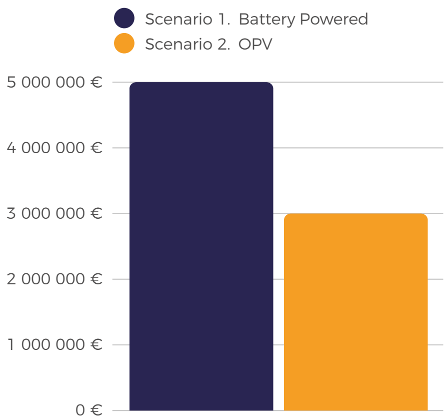



**Figure 1:** OPV can provides maintenance savings of up to 40% compared to systems that are battery powered.

The most well-known energy harvesting technologies are wind powered turbines and solar powered panels. These large-scale technologies are designed to operate in outdoor settings and generate relatively large amounts of energy to service buildings and campuses. They also feed into the traditional wired power infrastructure, powering devices that are plugged in. For low-power applications, turbines or panels are generally neither feasible nor cost-effective.

The ideal energy harvesting solution for devices operating in a controlled, indoor environment is to utilize ambient light. The available light to harvest within a building is typically on the order of 400 to 1000 lux. To put this in perspective, full daylight ranges from 10,000 to 25,000 lux, with direct sunlight reaching 100,000 lux or higher. Clearly, a different technology is needed that can operate efficiently in such 'low light' environments. In addition, the technology needs to be mature enough in terms of manufacturability to be able to support the high volume of devices that will be deployed over the next few years.

# Organic Photovoltaic Energy Harvesting

Organic Photovoltaic (OPV) energy harvesting was developed by Dracula Technologies to convert indoor ambient light to energy that meets the operating requirements for low power applications such as IoT wireless sensors, smart labels, electronic shelf labels, computer peripherals and other low-power electronic devices. Typically, low power devices spend most of the time in sleep mode. They wake infrequently to quickly sense and then transmit data, before dropping back into deep sleep. Because these devices use so little power, they can operate on just a trickle of energy, often at the µA or even nA levels.

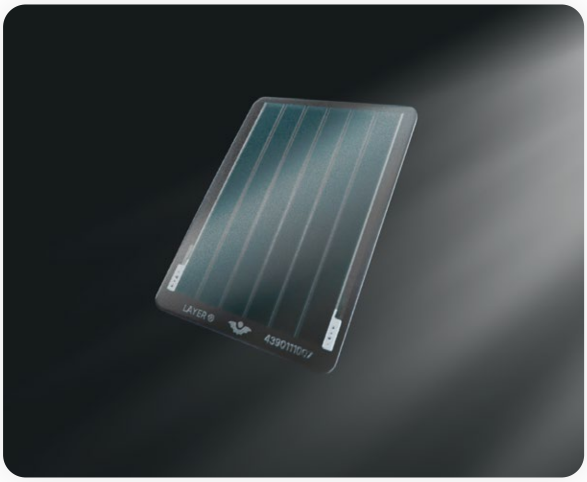


**Figure 2:** Image of a 3.6 V OPV module With six individual cells, this OPV module generates energy at 3.6 V.

OPV provides the trickle of energy needed to power low power devices operating in low light environments. The OPV cell generates energy, and the device stores it until the power is needed. The device wakes, consumes the power required to complete the task, then drops back into deep sleep, allowing the OPV cell to replenish the energy that was used.

The voltage supplied by an OPV module depends upon the number of cells it contains. Figure 2 shows a 3.6 V OPV module. As each cell achieves 0.6 V, six cells are needed for 3.6 V. The size of the cells determines the current with the general rule-of-thumb that each $cm^2$ can generate a certain amount of energy based on the available light (see Table 1). OPV modules can generate energy in light as low as 50 lux and even lower, with the minimum being 5 lux.

### Demokit Max performances between 50 - 1000 LUX

| Illumination (lux) | Voc (V) | Isc (µA) | Vmax (V) | Imax (µA) | Pmax (µW) |
|---|---|---|---|---|---|
| 50 | 3,12 | 19 | 2,45 | 15 | 37 |
| 200 | 3,47 | 76 | 2,80 | 64 | 179 |
| 500 | 3,67 | 190 | 2,95 | 162 | 478 |
| 1000 | 3,82 | 381 | 3,05 | 336 | 1'025 |

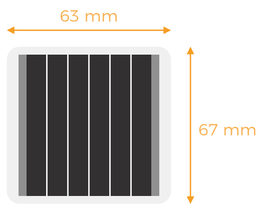
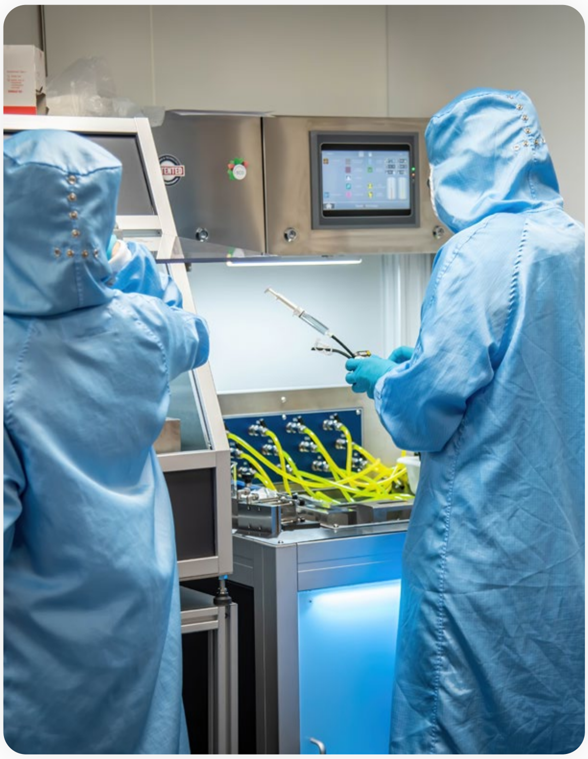



**Table 1:** This table shows the energy generation capabilities of OPV. The figures are measured using the standard Demo Kit Max provided by Dracula Technologies for evaluating OPV for low power applications.

# Storage Capacity vs Energy Need

There is a tendency in the electronics industry to think of energy / power in terms of capacity. For battery-based systems, the battery represents all the energy to which the system has access. Battery capacity is important because it determines the length of time between regular maintenance calls to replace batteries. Batteries can be thought of as a giant pool that is slowly drained. When it's empty, it's empty.

Energy harvesting changes how OEMs can think about power. Rather than calculating how much energy capacity is required so a device can operate several months or years (lifetime capacity), OEMs can evaluate systems based on how much energy the system needs to operate reliably (operating capacity). The operating capacity depends upon how often the system is active, how much energy the system consumes, and how quickly the OPV module can replenish the energy used. Because the OPV is regularly replenishing energy storage, the operating capacity is significantly less than the lifetime capacity. Put another way, instead of needing a giant pool to store energy, a sensor might just need a small bottle for storing its daily energy requirements.



This is how OPV can substantially reduce battery size in IoT sensors and other low-power applications. This also applies to rechargeable batteries. The sensors and other low-power applications appropriate for OPV simply don't require such large storage anymore.

For many IoT-based sensors, the battery represents the largest component in the system. The ability of OPV to reduce the size of the battery – or eliminate the battery altogether – means the overall size of the sensor can be reduced as well. In addition to lowering battery cost, OEMs can lower BOM costs by shrinking sensor size and how much plastic is needed to house the unit. Smaller – and lighter – systems also cost less to ship, furthering improving profitability.

# Volume Manufacturing

Dracula's unique inkjet precision printing technology provides a cost-effective way to quickly produce OPV. Built using LAYER® technology, OPV cells are printed flat to form a stack of organic layers. The cells are then encapsulated to protect the active materials in the cell. The cells can be printed in custom shapes and sizes for OEMs and device manufacturers to match the specific form factor and energy requirements of a device. Volume production OPV modules are available by the sheet or pre-cut to custom shapes for use by pick-and-place machinery.

**Figure 3:** LAYERVault is a companion technology to OPV, providing an electrical storage layer behind the OPV cell.

In addition to OPV for generating energy, Dracula Technologies offers LAYER®Vault as a companion technology to OPV. LAYERVault provides an electrical storage layer behind the OPV cell (see Figure 3). Depending upon the application, LAYERVault can provide enough storage to eliminate the need for a battery or component-based storage device (such as a capacitor).

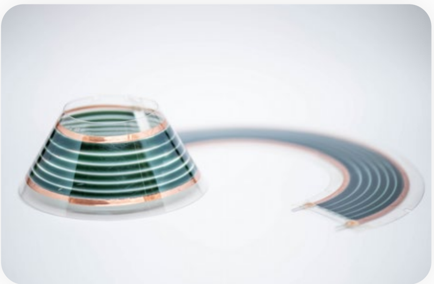
Dracula Technologies has volume production in place to provide OPV energy harvesting modules for mass industrial and consumer applications. The current factory has a yearly OPV capacity of 150 million $cm^2$. Major investment has already been committed to expanding capacity to ~1 billion $cm^2$ by mid-2026.

# Assessing OPV for Yourself

The first step to leveraging energy harvesting is to assess how OPV can work within your low power system. Dracula Technologies offers OEMs several options for evaluating OPV.

The OPV Demo Kit Max powers low power applications in indoor and mixed environments such as offices, homes, and warehouses. The OPV module generates up to 2.80 V, 64 μA, and 179 μW under 200 lux, making it ideal for powering indoor sensors, remote controls, trackers, and other smart devices.

The OPV Evaluation Kit combines the Demo Kit Max with a PMIC to regulate and optimize energy harvesting for applications operating in low light environments by providing stable power and extended device autonomy with a built-in voltage boost. Coming soon, Dracula Technologies will expand its range of OVP modules with different shapes and sizes.



To speed product development, Dracula Technologies has created an agile prototyping process for fast-tracking OPV prototypes specifically customized for an OEM's application. This allows developers to prototype with OPV cells in the shape and size they need even during early development stages. Once the design is finalized and the OPV cell is verified as meeting the system's energy needs, the specifications can be locked in for volume production.

Two key advantages of this agile prototyping process are its low cost and speed of delivery. Because of Dracula Technologies unique inkjet precision printing of OPV cells, no expensive mold or tooling is required. Specifying a custom OPV cell matching the voltage, current, and power requirements of the system takes just a few hours. Then, because OPV cells are printed, custom cells can be printed and delivered to OEMs in just 4 to 5 weeks.

Many low power applications do not need a power management IC (PMIC). For those that do require some kind of power management, the PMIC must be matched to the particular requirements of the application. Keeping the PMIC external to the OPV module ultimately maximizes both flexibility and power efficiency for developers. Dracula Technologies possesses the expertise to help you determine whether or not your application requires a PMIC

As energy harvesting technology continues to evolve, OPV is only becoming more efficient over time. For example, current OPV cells achieve a voltage of 0,7 V (Vmax). To support a higher voltage, multiples cells are connected together.

OPV-based designs will also benefit from the advantages of printed electronics. Today, some circuitry and antennae can be printed (i.e., integrated) with OPV cells. This will reduce component count, simplifying pick-and-place manufacturing. The roadmap for printed electronics is exciting, with many additional components under development.

# Changing the Way Electronics are Powered

Sustainability is a major concern for electronics manufacturers, and energy harvesting with OPV enables new levels of efficiency. Industry regulations are increasingly moving away from the use of disposable and even rechargeable batteries. Rechargeable batteries reduce battery waste but still require regular maintenance for battery replacement.

By providing reliable energy generation, OPV reduces or eliminates the need for batteries of all types, as well as reduces maintenance costs for battery replacement. And, unlike many batteries which rely on rare earth elements, OPV is made from organic materials that are sustainable and recyclable.

Another important change energy harvesting technology enables is that it breaks several of the limitations of traditional electronics. For example, 3 V is a common voltage for electronic components. However, 3 V comes from systems being designed to operate on two 1.5 V batteries. Low-power components are available for 2.5 V and 1.8 V, but even these are based on available storage cells.

The flexibility of OPV means OEMs have the freedom to utilize components operating across a wider range of voltages and currents. OPV cells by inkjet printing can be designed to deliver only the necessary amount of energy required for an application, thus maximizing efficiency.

Light energy harvesting technology will play a crucial role in enabling energy efficient smart devices and IoT systems. By eliminating or reducing the need for batteries, OEMs can build low power devices that reduce maintenance costs and lower TCO while improving sustainability. Organic Photovoltaic (OPV) technology from Dracula Technologies provides a compelling solution that is necessary to perfectly power your application without the need for any batteries in the future in a sustainable manner. Dracula Technologies' unique inkjet precision printers, combined with their agile prototyping capabilities, enables developers to prototype with a custom OPV module that is the same or close to the module that will be used in final production. And with new production resources coming online, OPV is the ideal choice for high-volume, low-power systems operating in indoor and low light environments.