WATTWAY: THE FIRST COST EFFICIENT PAVEMENT INTEGRATED PV FOR ELECTRICITY PRODUCTION

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ABSTRACT: The rapid expansion of photovoltaic (PV) energy faces constraints such as land use and biodiversity impacts. Integrated Photovoltaics (IPV), which embed PV modules directly into infrastructures, provide a solution by making use exisitng artificial surfaces. Among IPV technologies, pavement-integrated photovoltaics (PIPV) stand out for their large surface potential, high social acceptance, and structural resilience. Wattway, developed through a decade-long collaboration between Colas and CEA-INES, is the first PIPV system to combine robustness and cost efficiency. Its design leverages standard PV cell architecture while innovating in encapsulation materials and bonding techniques, resulting in a thin, glass-free module adapted to traffic loads. A comprehensive validation process, including IEC certification and road-specific tests, ensures a lifetime of 15 to 25 years. Continuous improvements have increased energy density by 51% and reduced installation costs through mechanized processes, achieving system prices below 2.5 €/Wp. Wattway now delivers competitive electricity costs for self-consumption applications in areas where conventional PV is difficult to deploy, such as cycle paths, marinas, and forecourts. Future developments aim to further reduce LCOE below 100 €/MWh through advanced module designs and work automation.

Keywords: Pavement PV, Ressource Efficiency, Landscape protection, LCOE (Levelized Cost of Electricity), Resilience, Acceptance criteria

1 CONTEXT

The massive development of photovoltaics (PV) [1], which reaches globally 1 TW in 2024 and 3.5 TW in 2030 [2] is already encountering, or will soon encounter constraints that limit further growth (lack of free areas, biodiversity impacts…) that PV on artificialized surface can circumvent.

Unlike ground mounted PV or canopy systems, dual use of photovoltaic modules on existing infrastructures has environmental benefits, avoiding land artificialization and using less concrete and/or metal, resulting in a **life cycle assessment benefit of more than 20% [3]**. This is why **Integrated PhotoVoltaic (IPV)** – where photovoltaic modules are directly incorporated into existing structures – has become a a major focus of research and development.

Figure 1 - Pavement-integrated photovoltaic illustrations, bicycle lane made near Amsterdam in Netherland (left), electrified seaport in South of France (right).

Pavement-integrated photovoltaics (PIPV) which comprise bicycle paths (1), parking lots, forecourts, piers, share all these advantages while also benefiting from:

- higher social acceptance, as the system is out of sight, not impacting the visual surroundings.
- structural resilience: PIPV systems are not subject to wind load, making them safe from storm damage.
- high available surface potential: unlike BIPV, PIPV faces fewer property constraints, enabling the development of large-scale solar installations at a lower price. Moreover, one road forecourt could supply multiple buildings, increasing self-consumption rate of the installation.

The chart (Fig.2) provides a qualitative comparison of IPV to other types of PV solutions such as Build-Applied (BA) systems (a superimposed solution) as well as floating and utility scale installations. In this chart, cost efficiency is assessed in relation to environmental impacts and risks.

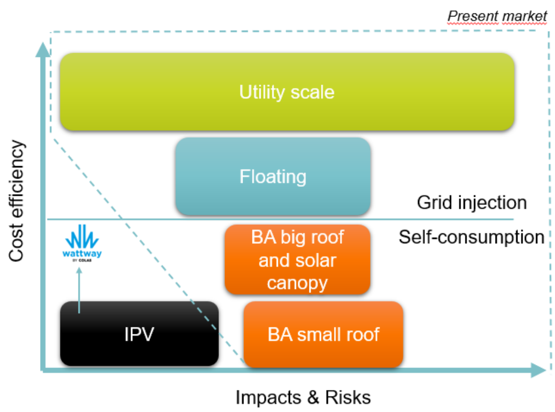

Figure 2 - Chart representing the cost efficiency vs impact & risks. IPV presents low risks and impacts but needs lower cost for massive adoption.

In IPV, the issue of cost may seem secondary compared to aesthetics and compliance with regulatory standards. These two aspects dominate Building Integrated PV (BIPV) as normative frameworks address critical issues such as fire resistance, wind resistance and more. Furthermore, these frameworks differ from country to country, resulting in fragmented markets, particularly across Europe. Pavement-integrated photovoltaics (PIPV) benefit from a simpler regulatory framework compared to BIPV, making cost the primary factor driving market size. The key question therefore is how the price of grid electricity compares to the cost of electricity generated by PIPV, considering both systems costs and long-term performance.

The two primary challenges for PIPV are then combining robustness and cost efficiency: Can a PV module be designed to withstand traffic loads [4,5,6], and can a profitable system be achieved with modules installed at suboptimal tilt angles (2)?

Wattway, developed through a **10-year collaboration between Colas and CEA-INES**, is the **first PIPV solution to successfully address both challenges**. Its innovations in **module design and installation processes** have made it possible to overcome these obstacles, delivering a durable and economically viable solution.

2 DESIGN

Wattway's module design strategy is to align with mainstream PV technology for cells and interconnect, while differentiating through innovative encapsulation materials. We use a standard electrical architecture featuring PERC cells, soldered strings of half-cut cells and a butterfly layout.

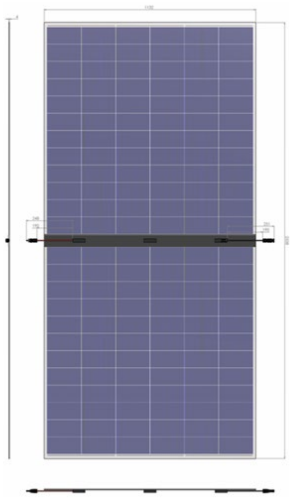

Figure 3 - Wattway Module 475 GC Electrical layout

The key innovations lie in the materials stack - eliminating glass and using specifically selected encapsulants -, in the top coating for skid resistance and in the glue-based bonding to the pavement. Module thickness is 4 mm and weight less than 6,5 kg/m^2.

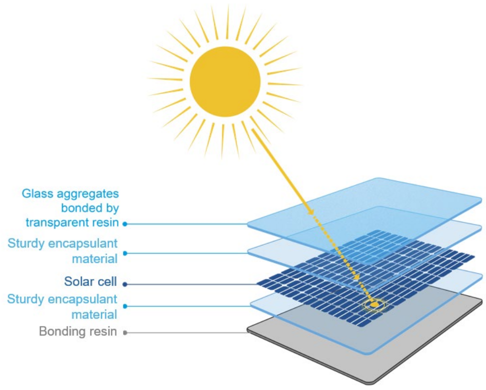

Figure 4 - Schematic representation of Wattway PIPV system.

3 ROBUSTNESS, PV/VALIDATION

Through a decade of module engineering and field feedback (3), we have developed a validation process to ensure 15 to 25 years lifetime (depending on traffic) for our PIPV solution, combining tests from PV and road-specific protocols. In 2024, Wattway became the first and only PIPV module to obtain certification according to the IEC61215 and IEC61370 standards for PV products.
IEC certification alone is not sufficient to validate a product integrated into pavement under traffic conditions. Therefore, we add more rigorous road-specific tests, mechanical ones as well as combined climatic-mechanical tests:

- Rutting: no deformation of the module after 1-million-wheel passages (4)
- High pressure cleaning: according to IPX9 standard (5)
- Immersion test: 500 hours of immersion in deionized water at ambient temperature
- Impact resistance: no damage to the PV cells (EL images) at IK9 level (6)
- Skid resistance: not slippery after 2 years of high traffic (7) according to legislation (Fig.5)

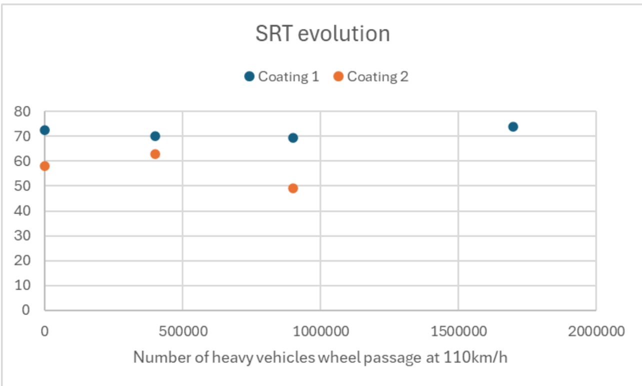

Figure 5 - Evolution of skid resistance test (SRT) as a function of the number of heavy vehicle wheel passages at 110 km/h. Two different coatings in compliance with road regulations are compared.

- Real traffic conditions ageing: no damage to the module or the cells (*in situ* EL, Fig. 7) after 400.000 passages in test campaigns (Fig. 6) done in France (8) and Japan (9).

Figure 6 – Real condition traffic ageeing with heavy vehicles in France (left) and in Japan (right).

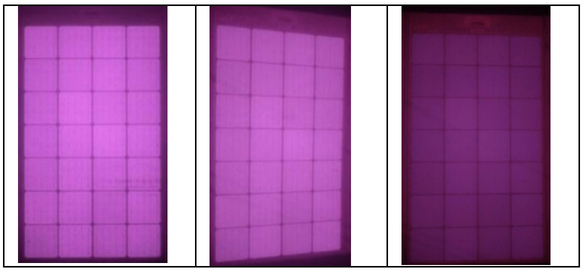

Figure 7 - Electroluminescence image after 200k, 400k and 600k passages

The combination of qualification tests and the creation of experimental sites around the world have enabled the validation of the technology: all components of Wattway PIPV solution (module stack, top coating, pavement bonding) successfully pass this validation process for the targeted 15 to 25 years lifetime.

4 COST EFFECTIVNESS

4.1 Cost of the system

Wattway began the development of prototypes in 2016. At that time, the main challenge was to deploy prototype technology from the laboratory in a public environment. The first PIPV panels were designed to withstand traffic while maintaining high transparency. The installation of these panels was very manual to ensure quality of the deployment. The electrical architecture was 60V to limit risks to users in case of prototype failure. The prototype installation costs were around €15/Wp, even for large demonstrators (330 kWp).

In subsequent years, we have driven Wattway's cost reduction through three main axes:

- Electrical architecture: with technological maturity to ensure users' safety, the architecture shifted from 60V to 1000V DC, allowing the use of standard PV electrical BOS equipment.
- Panel: the panel reached a standard PV panel size, lowering the PV panel unitary cost. It was designed to be compatible with a standard photovoltaic panel production line, decreasing fabrication costs. Bill of materials (BOM) has been optimized along with module lamination time.
- Mechanization of installation process: it has not only improved the quality of installation but also made it possible to increase panel size. Using civil engineering machines, we have developed a mechanized installation process of the module on the pavement; reducing the time for surface preparation and module bonding more than 10x.

This 10 years cost killing approach has divided by 6 Wattway's sales price from 15.2€/Wp in 2016 to 2.5€/Wp in 2026 (Fig 7), Since this has been achieved without any economies of scale in production, a clear potential for further cost reduction exists when sales volumes ramp up.

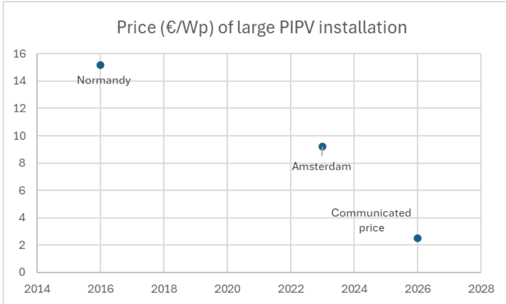

Figure 8 - Large scale installation price (€/Wc) of total Wattway installation as a function of the year

4.2 Performance

Over the past decade (2016 to 2025), the PV industry has achieved a 20 % improvement in cell efficiency. The Wattway has also profited from this increase. In addition, a strong push has been made to densify the solar cells grid and increase the front side transparency, without compromising on mechanical robustness of the system. This fine balance between materials choice and stack architecture has allowed a total module power density gain of 36% in Wp/m² from the initial 2016 prototype to the current 475 GC product [4] at 180 Wp/m².

Ultimately, in terms of performance, the key metric for the customer is energy production. To assess our performance over the years, we have monitored our largest installations and normalized their actual energy production to the condition of Versailles (France). The normalization includes shading correction from PVSYST and adjustments for yearly local irradiation compared to the irradiation level at Versailles. The energy produced was 97 kWh/year/m² by our Normandy installation in 2016, after renormalizing. Fig. 8 shows a 94% increase in areal energy production from 2016 to 2026.

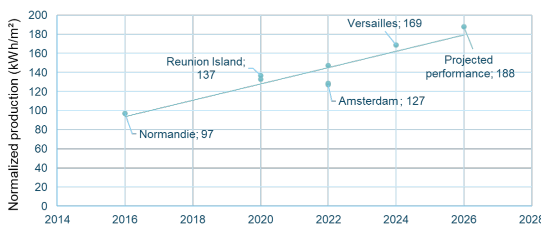

Figure 9 - Evolution of the normalized energy production density (kWh/m²) as a function of the years. Different production sites monitoring

As a result, we now reach a full system price below 2,5 €/Wp for a 200 kWp turnkey solution. Combining price and performance improvements, the kWh production cost decreased by a factor of 12.

At this price level, Wattway is today a cheaper solution for sourcing electricity than buying it from the grid electricity providers (10), for local self-consumption applications. For example, the levelized cost of energy (LCOE) for a 200 kWp bicycle path with 25 years lifetime in Florence is 127 €/MWh.

6 PERSPECTIVES

Wattway PIPV solution is today a cost-efficient solution for electricity production, it is proven robust and IEC-certified. We continue to pursue improvements in performance and cost, e.g. in module stack optimization and automation of the installation process. A TOPCon Wattway module is in development. Our target is to reach a LCOE below 100 €/MWh across a large part of Europe (excluding the northernmost countries) by 2030.

5 NOTES

(1) In Europe for example, 10 % of the 190 000 km bicycle path networks alone could harbour more than 8 GWp
(2) In European latitudes, energy production of a module flat on the ground is 14% lower in South Italy and 19 % in North UK compared to an optimal tilted one.
(3) Over this period, more than 100 experimental and commercial sites have been deployed in different weather (cold, moderate, hot, humid…) and traffic conditions
(4) NF EN 12697-22 standard: 0,6 MPa tire pressure, back and forth at 5 km/hour (worst case)
(5) IEC 60529 standard: 110 bars with 95°C water , no delamination or degradation of the module
(6) EN 62262 standard: resistant to 20 joules impact test
(7) EN 1824 standard: SRT > 0.45 after 2 millions wheel passages on a real motorway (RN2)
(8) A circulating arm driving an 8 tons axle tree resting on 2 truck tires (equivalent to 16t axle truck) at 50 km/hr
(9) Tele-operated 13t axle trucks
(10) Depending on local solar irradiation (the higher the better) and end user electricity price.

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