D8.2. Policy recommendations

PHOTOSINT

PHOTOELECTROCATALYTIC SYSTEMS FOR SOLAR FUELS ENERGY INTEGRATION INTO THE INDUSTRY WITH LOCAL RESOURCES

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▪ *Have followed the required conventions in referencing the thoughts, ideas and texts made outside the Project.*

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NOMENCLATURE

AaaS	Auctions-as-a-Service
CAPEX	Capital Expenditure
CfDs	Carbon pricing and carbon contracts for difference
CID	Clean Industrial Deal
CISAF	Clean Industrial State Aid Framework
CO_2	Carbon Dioxide
EHB	European Hydrogen Bank
EU	European Union
GHG	Greenhouse Gas
H_2	Hydrogen
LCA	Life Cycle Analysis
MeOH	Methanol
OPEX	Operating Expenditure
PEC	Photoelectrochemical Cell
PPAs	Purchase Agreements
PtX	Power-to-X
RCF	Recycled Carbon Fuel
PV	Photovoltaic
RED	Renewable Energy Directive
RFNBO	Renewable Fuel of Non-Biological Origin
R&I	Research and Innovation
STF	Solar-To-Fuel
TCTF	Temporary Crisis and Transition Framework
TRL	Technological Readiness level
VRE	Variable Renewable Energy

EXECUTIVE SUMMARY

This report presents policy recommendations arising from the PHOTOSINT project, a Horizon Europe initiative focused on advancing photoelectrocatalytic (PEC) systems for the direct solar-driven production of renewable hydrogen and methanol. The project aims to demonstrate how innovative PEC cell designs can convert sunlight, wastewater and captured CO_2 into sustainable fuels, thereby supporting the decarbonisation and energy independence of Europe's energy-intensive industries.

Between 2023 and 2025, the policy landscape underpinning renewable fuels evolved significantly. What began as a research-driven agenda has transitioned into a regulatory framework centred on certification, market creation and industrial deployment. Key developments include the introduction of RFNBO (Renewable Fuels of Non-Biological Origin) certification rules, electricity-market reform enabling long-term PPAs (Purchase Agreements) and Contracts for Difference, the establishment of the European Hydrogen Bank (EHB), and new state-aid provisions under the Clean Industrial Deal and the Clean Industrial State Aid Framework (CISAF). Together, these measures reinforce the EU's shift towards decarbonisation, energy security, and strategic industrial competitiveness.

For PHOTOSINT and related PEC technologies, these developments create both opportunities and constraints. Compliance with RFNBO rules - covering additionality, temporal and geographical correlation, and lifecycle emissions - has become essential for market access and eligibility for deployment funding. The EHB now offers substantial support for renewable hydrogen production, but competition strongly favours mature electrolysis technologies. Electricity-market reforms improve access to stable, low-carbon electricity, while CISAF opens pathways for Member States to co-fund industrial demonstrators, manufacturing capacity and clean-technology roll-out. Nevertheless, administrative burdens, supply-chain uncertainties and technology bias remain challenges for emerging PEC solutions.

In response to this landscape, the report proposes targeted policy recommendations and the creation of a policy brief to accelerate the commercial readiness of PEC-based solar-fuel technologies. These include formally recognising PEC pathways in EU and national legislation, adapting RFNBO certification rules to accommodate direct solar-to-fuel processes, and developing harmonised standards for PEC performance and durability. The report further recommends tailored support mechanisms, such as dedicated innovation windows within the EHB, CISAF-funded pilot plants, and regional testbeds, to close the gap between laboratory achievements and industrial deployment.

Industrial integration is identified as a critical enabler. The report advocates coordinated planning across the energy, water and chemical sectors, incentives for industrial symbiosis models using wastewater and CO_2 streams, and support for retrofitting existing facilities with solar-driven fuel systems. Additionally, it calls for strengthened demand signals through consistent implementation of RFNBO quotas, carbon contracts for difference, and expanded green public procurement. Developing skills, manufacturing capacity and circularity pathways for PEC materials is also recommended to secure Europe's long-term technological leadership.

Overall, PHOTOSINT is on its way to demonstrate that solar-driven PEC systems hold considerable potential to contribute to Europe's decarbonisation goals, industrial competitiveness and energy resilience. Realising this potential will require an enabling regulatory environment, targeted deployment funding, supportive market frameworks and coordinated cross-sectoral action. The recommendations presented in this report aim to ensure that Europe can fully leverage its scientific strengths in artificial photosynthesis and next-generation solar fuels, transforming them into commercially viable and strategically valuable industrial solutions.

1. INTRODUCTION

1.1 Description of the document and pursue

The decarbonisation of Europe's energy-intensive industries increasingly depends on innovative renewable-fuel technologies capable of reducing emissions while strengthening energy security and competitiveness. Within this context, the PHOTOSINT project advances a novel approach based on PEC (photoelectrocatalytic) systems that convert sunlight, wastewater and captured CO_2 into hydrogen and methanol. These solar-driven pathways offer the potential for decentralised, resource-efficient and low-carbon fuel production, complementing existing approaches such as electrolysis and supporting the long-term objectives of the European Green Deal, the EU Hydrogen Strategy and REPowerEU.

This deliverable provides policy recommendations based on PHOTOSINT's outcomes and situates the project within the evolving EU policy landscape. Since the project's launch in September 2023, the regulatory environment for renewable fuels has shifted decisively from high-level ambition to detailed implementation. New rules, including RFNBO (Renewable Fuel of Non-Biological Origin) certification criteria under the Renewable Energy Directive, electricity-market reforms, and the introduction of the Clean Industrial Deal, now shape the feasibility, cost structure and regulatory compliance requirements for emerging renewable-fuel technologies. For PEC systems, understanding and aligning with these frameworks is essential to ensure that technological achievements are matched with market and policy readiness. To support this analysis, Table 1 summarises the most relevant EU-level policies influencing PEC-based fuel production, renewable-fuel certification, market integration and industrial scaling.

These frameworks are central to assessing the industrial potential of PEC technologies. The RFNBO Delegated Acts define what qualifies as renewable hydrogen or e-fuels, including lifecycle-emissions thresholds and strict rules for renewable-electricity sourcing. Electricity-market reforms introduced between 2024 and 2025 will influence how PEC-based production interacts with the grid, how auxiliary electricity can be contracted, and how industrial plants can secure a stable, compliant and affordable renewable-energy supply. In parallel, the Clean Industrial Deal and its supporting Clean Industrial State Aid Framework (CISAF) create new opportunities for Member States to fund clean-tech deployment, including pilot plants, first-of-a-kind manufacturing capacity and industrial retrofits. Together, these instruments reflect an EU-wide shift towards accelerating clean-technology deployment and strengthening Europe's industrial resilience.

Positioning PHOTOSINT within this landscape highlights both opportunities and challenges. On the one hand, PEC systems align strongly with EU priorities: they support renewable-hydrogen goals, contribute to circular-carbon strategies by using CO_2 as a feedstock, and offer potential for local production of strategic energy carriers. On the other hand, emerging technologies may face barriers when regulatory frameworks are designed primarily around mature electrolysis-based pathways. Clear recognition of PEC routes in legislation, certification mechanisms adapted to direct solar-to-fuel processes, and targeted funding for early industrial demonstrations will be essential for enabling market integration.

This introduction, therefore, frames the deliverables' broader purpose: to analyse how EU-level policies affect PHOTOSINT and similar PEC-based initiatives, and to propose strategic recommendations that support their industrial uptake. By bridging scientific progress with regulatory, economic and industrial considerations, the report aims to ensure that PEC technologies can evolve from laboratory successes to scalable, commercially viable contributors to Europe's clean-energy transition.

Table 1. Key EU-level relevant policy and regulatory frameworks

Policy / Document	Relevance to PHOTOSINT / Industrial PEC Integration
EU Hydrogen Strategy (2020)[1]	The starting strategic roadmap for hydrogen in the EU sets out the EU's ambition for renewable hydrogen deployment, relevant for framing H_2 production as part of the EU's clean hydrogen ecosystem.
Renewable Energy Directive (RED / RFNBO rules, including Delegated Acts 2023/1184 & 2023/1185)[2]	Since PHOTOSINT aims at producing H_2 (and potentially fuels like methanol) using renewable energy (sunlight) and CO_2/wastewater, these rules define what qualifies as 'renewable hydrogen of non-biological origin (RFNBO)' and set lifecycle emissions thresholds. Understanding these criteria and certification mechanisms is essential.
Electricity Market Design Reform (as updated by the EU in 2024–2025)[3]	Integration of PEC-based hydrogen/methanol production into the grid and electricity supply depends on how electricity markets are structured (tariffs, flexibility, renewables integration, demand response). This reform impacts how industrial PEC plants could draw power or operate in low-cost periods.
Clean Industrial Deal (2025), including the associated Clean Industrial State Aid Framework (CISAF)[4]	Because PHOTOSINT aims at decarbonising the chemical industry and energy-intensive industrial processes (e.g., via solar-driven H_2 / MeOH), this deal and its financial/support mechanisms are central. CISAF will likely govern potential subsidies, state aid, and public support for PEC-based clean-tech deployment.
State aid rules relevant for clean energy and hydrogen projects (previously under the Temporary Crisis and Transition Framework (TCTF), now succeeded by CISAF)[5]	Given the high CAPEX and uncertain payback of novel solar-PEC systems, state aid frameworks will likely be crucial to make industrial-scale deployment feasible. Understanding permitted aid intensities, criteria, and conditions is necessary.
EU's energy-raw-materials and industrial strategy via EU Energy and Raw Materials Platform (2025)[6]	This new platform aims to coordinate hydrogen, methanol, and other energy-vector supply and demand. Given that PHOTOSINT targets methanol and hydrogen as energy vectors, the Platform's treatment of methanol (e-methanol / synthetic fuels) and hydrogen creates a relevant market/policy context.

[1] https://ec.europa.eu/commission/presscorner/api/files/attachment/865942/EU_Hydrogen_Strategy.pdf
[2] https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen/renewable-hydrogen_en
[3] https://observatory.clean-hydrogen.europa.eu/eu-policy/electricity-market-design-reform
[4] https://competition-policy.ec.europa.eu/about/contribution-clean-just-and-competitive-transition_en
[5] https://observatory.clean-hydrogen.europa.eu/eu-policy/state-aid
[6] https://energy.ec.europa.eu/topics/energy-security/eu-energy-and-raw-materials-platform_en

1.2 WPs and tasks related to the deliverable

D8.2 – Policy recommendations is in the scope of *Task 8.3 – Ethic issues management and policy recommendations* within *WP8. Project Management and coordination*. The general aim of Task 8.3 can be divided into the following 3 points:

1. The monitoring of all possible administrative issues related to the facilities' authorizations and compliance with all legal requirements according to relevant local/national guidelines/legislation.
2. The management of GDPR compliance in the PHOTOSINT project.
3. The creation of a document providing a set of policy recommendations based on the outcomes of the project.

The first two points were covered within *D8.1 – Ethic requirements report* submitted in M20 (April 2025) as a sensitive document.

During this period, the work has primarily focused on the last point. This report analyzes relevant policies and other key factors related to integrating the PEC system into the industry. The emphasis is on government policies, but also considers private sector policies in energy production, adopting a broader perspective.

2. THE PHOTOSINT PROJECT AND ITS REGULATORY CONTEXT

2.1 About the PHOTOSINT project

The PHOTOSINT project, named *PHOTOelectrocatalytic systems for Solar fuels energy INTegration into the industry with local resources*, is an initiative granted under the Horizon Europe call HORIZON-CL5-2022-D3-02 and, specifically, topic *HORIZON-CL5-2022-D3-02-06: Direct renewable energy integration into process energy demands of the chemical industry*.

The PHOTOSINT project offers solutions to the chemical industry's challenges in incorporating renewable energy into its processes. It aims to develop sustainable methods for producing hydrogen and methanol as energy carriers, using only sunlight, wastewater, and CO_2 as inputs, thus increasing industry self-sufficiency. The approach relies on solar-driven artificial photosynthesis, focusing on creating new catalytic materials that are earth-abundant and refining existing ones to enhance catalytic efficiency. The design of the PEC cell will be optimized to maximize STF (Solar-To-Fuel) efficiency. Additionally, PHOTOSINT will innovatively concentrate and illuminate the semiconductor surface, expanding the light collection area at similar CAPEX, and incorporate a heat exchange system between the semiconductor and electrochemical cell to boost overall energy efficiency and reduce OPEX. Low-cost, advanced perovskite solar PV cells will also be integrated to power the electrocatalyst process.

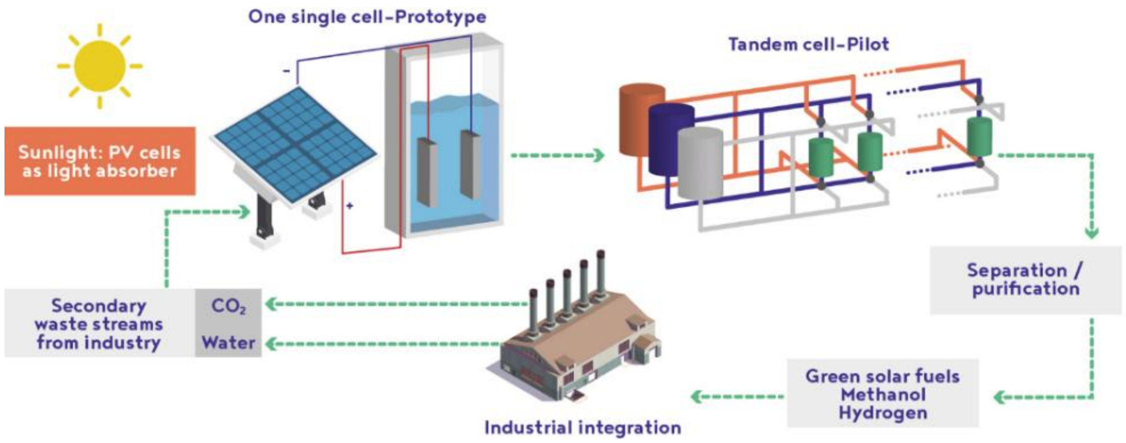

Figure 1. PHOTOSINT overall concept

PHOTOSINT is a promising project, despite limited existing research and low production rates of target products. The project will focus on studying catalysts to harness sunlight energy for industrial use. The best catalysts identified will be incorporated into prototypes. These results will guide the scaling-up process in pilot plants using tandem PEC cells. This progression is critical to evaluate the feasibility of industrial-scale implementation, enhancing the competitiveness of renewable energy technologies and promoting energy independence. Additionally, MeOH and H_2 will be tested in industrial settings with the goal of achieving TRL4 by the project's end.

The PHOTOSINT initiative brings together 14 partners from 8 European countries (Spain, France, Sweden, Estonia, Italy, Slovenia, Greece, and Romania). It is a well-organized consortium with clearly defined responsibilities designed to maximize synergies, avoid duplication, and ensure the smooth progress of all project activities. With a total budget of 4,993,752.51 EUR, the project will run for 48 months starting in September 2023.

More information about the PHOTOSINT project progress can be found on the following sources:

Source	Link
Project website	https://www.photosint.eu/
CORDIS	https://cordis.europa.eu/project/id/101118129
ZENODO	https://zenodo.org/communities/photosint-resources/records?q=&l=list&p=1&s=10&sort=newest
SOCIAL MEDIA	
LinkedIn	https://www.linkedin.com/company/photosint/posts/?feedView=all
Youtube	https://www.youtube.com/watch?v=-w7oKLhbdLY&t=96s
X	https://x.com/Photosint_eu

2.2 Policy drivers underpinning the PHOTOSINT topic

The Horizon Europe topic *HORIZON-CL5-2022-D3-02-06: Direct renewable energy integration into process energy demands of the chemical industry*[7] was developed within a policy context where the European Union aimed to accelerate the decarbonization of energy-intensive industries, achieve energy independence, and promote new renewable energy carriers and processes. The topic called for research and innovation focused on replacing fossil-based process energy in chemical production with renewable energy sources, including innovative direct-integration methods (such as solar-driven conversion routes).

In this policy context, the European Commission aimed to support projects that could show how renewable energy sources, especially solar-based technologies, could be effectively integrated into energy-intensive industrial processes. The call, therefore, emphasized not only the advancement of fundamental knowledge - such as catalysis, materials development, and process intensification - but also the need to develop practical, scalable, and industry-relevant integration pathways. This dual focus reflected the EU's goal to go beyond laboratory-scale proofs of concept and move toward solutions capable of supporting future commercial deployment. Specifically, the call was motivated by the understanding that meeting the goals of the European Green Deal, the EU Hydrogen Strategy and REPowerEU would require innovative, high-efficiency systems for producing and utilizing renewable fuels and energy carriers directly within industrial facilities. Consequently, the topic prioritized projects capable of demonstrating credible techno-economic potential, compatibility with existing industrial infrastructure.

As just mentioned, two interconnected policy instruments formed the strategic basis for HORIZON-CL5-2022-D3-02-06. First, the **European Green Deal** (COM(2019) 640)[8] articulated the EU's long-term goal of achieving climate neutrality by 2050. It identified energy-intensive industries as a key sector for decarbonization and emphasized the need for innovation, technological deployment, and funding to cut greenhouse gas emissions across the economy. The Green Deal explicitly highlighted interventions that combine energy efficiency, renewable energy deployment, and circular economy strategies as central to European industrial policy. Second, the **EU Hydrogen Strategy** (2020)[9] boosted political support for clean molecules and fuels as integral parts of the energy transition. The Strategy positioned renewable hydrogen and related carriers as vital for decarbonizing sectors where direct electrification proves challenging. It thus established a policy priority to invest in research on various hydrogen production and

[7] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2022-d3-02-06
[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN
[9] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX%3A52020DC0301

fuel-synthesis technologies, including innovative solar-driven routes and PtX (Power-to-X) concepts. The combined framing of the Green Deal and the Hydrogen Strategy created a policy window for research and innovation funding to support technologies that convert renewable energy directly into process fuels and energy carriers for industry.

A third and catalyzing event was **REPowerEU** (March 2022)[10]. REPowerEU responded to the energy-security shock caused by Russia's invasion of Ukraine by speeding up EU commitments to diversify and grow renewable energy and local fuel production, including hydrogen and PtX. Therefore, REPowerEU increased urgency and political backing for research and deployment strategies that cut fossil-fuel imports, further supporting the inclusion of topics aimed at directly integrating renewable energy into industrial process energy needs.

Taken together, these policy drivers shaped a research landscape where technologies like those proposed under PHOTOSINT are viewed not only as long-term options but also as vital contributors to Europe's medium- and short-term strategic goals. By linking renewable energy integration with industrial competitiveness, the EU positioned innovation in solar-driven fuel production and PEC systems as part of a larger transformation of the industrial ecosystem. This transformation includes decarbonization, resource efficiency, strategic autonomy in energy supply, and resilience of the chemical sector, all central themes in the current EU industrial strategy. The Horizon Europe topic was therefore designed to speed up progress where policy ambition, industrial needs, and technological opportunities intersect.

Moreover, including this topic within Cluster 5 reflected the European Commission's wider goal to enable cross-sectoral collaborations and support technologies that bridge renewable energy generation with industrial energy use. The call acknowledged that achieving deep decarbonization of the chemical industry will need comprehensive approaches that combine materials science, process design, renewable-energy harvesting, and systems-level engineering. The policy environment thus provided a strong mandate for projects that demonstrate integrated, interdisciplinary solutions. In this sense, PHOTOSINT directly aligns with the EU's vision of supporting innovation that is scalable, circular, and adaptable to evolving regulations. As a result, the project's outcomes could not only advance scientific understanding but also shape future policies and help Europe move toward climate-neutral industrial production.

[10] https://commission.europa.eu/topics/energy/repowereu_en

3. THE PRESENT POLICY LANDSCAPE (2023 - 2025)

Since the publication of the call for proposals under Horizon Europe for topic HORIZON-CL5-2022-D3-02-06, the European policy environment has experienced significant changes. What was once mainly an R&I-focused setting, designed to encourage early-stage technological development, has evolved into a more mature ecosystem emphasizing certification, market creation, deployment support, and industrial scaling. These shifts reflect the urgent need to decarbonize, ensure energy security, and rapidly deploy renewable fuels and clean technologies. For projects like PHOTOSINT, which aims to deploy solar-driven, PEC systems to produce hydrogen and methanol, the advancements between 2023 and 2025 bring crucial implications: opportunities and challenges, new funding sources, but also stricter regulatory requirements and a higher standard for viability.

Comparing the EU policy environment, it can be said that it shows both continuity and transformation. The 2022 R&I-oriented framework was built upon long-term climate ambitions and technological optimism. By 2025, the EU has matured its regulatory, market, financial and industrial frameworks to actively support deployment, scale-up, market formation, and industrial competitiveness.

The key differences (summarized also in Table 2) are the following:

- ✓ **From policy ambition to operational regulation.** In 2022, hydrogen and renewable fuels were broad policy targets. Now, RFNBO certification rules (2023) operationalise those targets, making compliance a concrete technical and regulatory condition.
- ✓ **From grants to market and state-aid instruments**. Earlier, Horizon/EU R&I grants were the main support for innovation. Now, the EHB (European Hydrogen Bank), CISAF, national AaaS (Auctions-as-a-Service) schemes and long-term PPAs (Purchase Agreements) provide funding streams oriented toward industrial-scale deployment.
- ✓ **From R&I projects to industrial-scale demonstration and manufacturing capacity building**. New policies explicitly treat clean-tech manufacturing, large-scale electrolysers, synthetic-fuel plants and domestic value-chains as core to European industrial competitiveness.
- ✓ **From idealised renewable energy supply to regulated, traceable renewable input**. The RFNBO rules enforce additionality, correlation and lifecycle standards. Electricity sourcing cannot now be treated as incidental or assumed to be low-carbon.
- ✓ **From climate-only framing to energy-security & strategic-industrial framing**. Renewable fuels are no longer just for decarbonisation, but also for resilience, supply-chain independence and strategic autonomy.

In sum, the transformation reflects the EU’s determined shift from supporting ‘what if’ research toward enabling ‘what works’ industrial deployment.

Table 2. Key differences between the original policy context and today

2022 Context (Call Creation)	2025 Context (Current Landscape)
Focus on Research & Innovation, early technological development.	Strong push for deployment, market creation, and industrial scale-up.
Hydrogen is a strategic priority, but certification rules are not fully defined.	Full RFNBO certification regime in force. Strict rules shape technology viability.
Funding mainly through R&I programmes.	Deployment funding through Hydrogen Bank, auctions, CISAF-enabled state aid.
Less emphasis on electricity market structures.	Reformed electricity market enabling PPAs and CfDs. Crucial for PEC.
Emphasis on decarbonisation goals.	Decarbonisation + energy security + EU industrial competitiveness.

The following subsections analyze in detail the five most important developments: (1) RFNBO and lifecycle certification rules; (2) transition from R&I grants to deployment instruments (notably the EHB); (3) reforms in electricity markets and contracting frameworks; (4) updated state aid rules under the CISAF and CID (Clean Industrial Deal); and (5) a growing focus on energy security, supply chain resilience, and industrial competitiveness.

3.1 RFNBO and Lifecycle Certification Rules

Since PHOTOSINT began, the most significant policy change has been the formalization of definitions and requirements for what qualifies as a 'renewable fuel of non-biological origin' (RFNBO). In June 2023, the European Commission officially adopted two delegated acts under the Renewable Energy Directive[11]: RED II and RED III. These acts detail the standards and criteria for classifying hydrogen and other energy carriers as RFNBOs, and the methods for calculating their lifecycle GHG (Greenhouse Gas) emissions savings.

The 2023 Delegated Regulation (EU 2023/1184)[12] defines the conditions under which hydrogen or hydrogen-based fuels qualify as RFNBOs. Among the critical criteria are:

- ✓ **Additionality:** Renewable electricity used for hydrogen (or synthetic fuel) production must come from 'new and additional' renewable energy sources.
- ✓ **Temporal correlation:** The renewable electricity must be produced at the same time as the hydrogen (or fuel) production, or through defined compensation mechanisms.
- ✓ **Geographical correlation**: Electricity production and fuel generation must occur within a defined proximity or region to ensure grid- and energy-system integrity.
- ✓ **GHG emissions savings threshold**: The companion Delegated Regulation (EU 2023/1185)[13] sets minimum lifecycle emissions savings thresholds for RFNBOs

[11] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC
[12] https://eur-lex.europa.eu/eli/reg_del/2023/1184/oj/eng
[13] https://eur-lex.europa.eu/eli/reg_del/2023/1185/oj/eng

and RCFs (Recycled Carbon Fuels). Only fuels that meet these thresholds qualify for regulatory benefits.

These criteria translate previously broad political goals, like renewable hydrogen and synthetic fuels, into specific compliance requirements. For PEC-based projects such as PHOTOSINT, this means that conceptual novelty or lab-scale performance alone is no longer enough. The entire production process, from energy sourcing to fuel output, must be designed for compliance, and documentation, certification, and traceability become crucial.

For technologies integrating intermittent renewable energy sources like solar power, the additionality, timing, and geographical correlation requirements can present challenges. Unless the renewable energy is either directly coupled (such as on-site PV + PEC) or secured through long-term renewable energy PPAs from new facilities, downstream hydrogen or methanol production might not qualify as RFNBO.

Furthermore, lifecycle GHG accounting must encompass all emissions: upstream manufacturing of materials, operations, and processing. For a new PEC + methanol synthesis process (using CO_2 or wastewater feeds), developers need to gather comprehensive LCA (Lifecycle Analysis) data demonstrating that the net emissions (production plus use) meet or fall below the threshold. The compliance burden is therefore much higher than in the 2022 R&I context, and certification becomes essential to attract deployment funding, off-take agreements, or market premiums.

On the positive side, implementing these delegated acts offers regulatory certainty. Before their adoption, hydrogen and synthetic fuel producers faced an ambiguous and rapidly changing regulatory landscape. With the 2023 acts in place, investors, project developers, and off-takers can plan with confidence. They know the standards they must meet, what constitutes a compliant fuel, and what certification is necessary. This clarity reduces regulatory risk and enhances the bankability of renewable fuel projects.

In this way, RFNBO certification functions both as a gatekeeper and a guarantee: it acts as a gatekeeper by possibly excluding non-compliant technologies from subsidies, auctions, or renewable quotas; and as a guarantee, because certified fuels gain legitimacy in the emerging EU hydrogen and fuel markets, providing access to funding, off-take agreements, and investor confidence.

3.2 From R&I Grants to Market Deployment Instruments

Another major transformation in the EU policy framework is the shift from predominantly R&I funding to market-oriented deployment instruments. Central in this shift is the establishment of the EHB (European Hydrogen Bank)[14], which aims to facilitate large-scale renewable hydrogen production by bridging the cost gap between renewable and fossil hydrogen.

The EHB is designed around four pillars:

- ✓ Domestic pillar
- ✓ International pillar
- ✓ Transparency and coordination pillar
- ✓ Support-instruments coordination pillar.

For the domestic pillar, the EHB provides a fixed premium (€/kg) for verified and certified renewable hydrogen (RFNBO hydrogen) produced, for a period of up to ten years.

[14] https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen/european-hydrogen-bank_en

The first competitive auction, 'IF23 Auction'[15], was launched in Autumn 2023 and ran until February 2024. The second, 'IF24 Auction'[16], closed in February 2025, selecting a new set of projects. The second auction awarded nearly 992 million EUR across 15 renewable hydrogen production projects in five countries, expected to generate approximately 2.2 million tonnes of renewable hydrogen over ten years, and thereby avoid more than 15 million tonnes of CO_2 emissions.

Additionally, the mechanism allows Member States to participate via AaaS, thereby combining national and EU-level funds. For example, in April 2025, the Commission approved a 400 million EUR Spanish State-aid scheme under AaaS to support electrolyser capacity and green hydrogen production[17].

At the time PHOTOSINT was funded (2022), the main financial support for such projects likely came from R&I grants under Horizon Europe or similar programs, which are non-commercial, early-stage, proof-of-concept funding. The goal was long-term: successful demonstration, technology development, and potential scale-up.

Now, with the EHB established, a credible pathway exists for early commercial deployment: projects that can achieve RFNBO certification and show scale potential can apply for significant financial support, which could make them cost-competitive with fossil hydrogen. This change reduces one of the biggest barriers, especially for hydrogen-based business models targeting industrial off-take, fuel markets, or PtX value chains.

Furthermore, the EHB is more than just a subsidy channel; it acts as a market creation mechanism. By supporting certified renewable hydrogen production, the EU aims to establish a functioning hydrogen market with supply, demand, price formation, and long-term contracts. This marks a major step forward in maturity compared to 2022, when hydrogen was mainly viewed as a future goal rather than an immediate commodity.

However, this development favours electrolyzer-based hydrogen production because of its maturity, proven track record, and relatively well-understood techno-economic profile. For innovative methods such as solar-driven PEC systems, artificial photosynthesis, or integrated solar + CO_2-to-methanol conversion, the challenge is greater. They must first obtain RFNBO certification and then prove scalability, reliability, and cost competitiveness to compete in hydrogen auctions. Fixed-premium support helps, but only if the technology is sufficiently mature and demonstrable. For many early-stage projects, a hybrid approach might be necessary: combining PEC research with PV or renewable sources, or developing small demonstration electrolyzer + PEC hybrid systems to move toward commercial readiness.

Therefore, while the EHB expands deployment options beyond traditional R&I grants, it also sets a higher standard. Only projects that can produce certifiable, scalable, reliably renewable hydrogen (or its derivatives) will have a realistic chance of success.

3.3 Electricity Market Reforms

Alongside developments in hydrogen-fuel policies, the European electricity market has seen major reforms and regulatory updates, which influence how renewable electricity is sourced, used, and managed. Thus, it affects the feasibility of renewable-fuel production processes that rely on VRE (Variable Renewable Energy), such as solar-powered PEC systems. The production of renewable fuels (hydrogen, methanol, synthetic hydrocarbons) fundamentally depends on access to low-carbon electricity. For

[15] https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/calls-proposals/if23-auction-renewable-hydrogen-production_en
[16] https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/calls-proposals/if24-auction_en
[17] https://www.enerdata.net/publications/daily-energy-news/eu-commission-approves-eu400m-spanish-aid-scheme-green-h2-auctions.html

intermittent renewables (like solar PV and wind), this creates temporal, spatial, and contractual challenges. The production must be aligned in time and location with renewable generation, or contracts and guarantees must ensure compliance through accounting. Since the 2023 RFNBO rules require additionality and correlation, obtaining compliant electricity is a complex contractual matter as it demands legal clarity, long-term supply guarantees, and thorough documentation.

Additionally, revenue and price risks are high: renewable-fuel producers need stable electricity supplies at predictable costs over long periods to stay viable. Volatile electricity markets, spot-price fluctuations, or short-term contracts can cause hydrogen or methanol costs to vary, weakening competitiveness and bankability.

Between 2024 and 2025, the EU introduced reforms to the electricity market through updates to the internal market design, grid regulation packages, and related directives aimed at enabling long-term PPAs, Contracts for Difference (CfD)-like structures, and encouraging flexibility and storage to support high shares of VRE. These reforms aim to reduce volatility and establish stable price signals, making renewable energy procurement more predictable for large-scale projects and major users. Although the specific legal texts differ by Member State and not all countries have fully adopted these reforms, the overall trajectory is clear: long-term contracting and the integration of renewables, storage, and flexibility are becoming more standardized and supported[18, 19, 20].

For producers of renewable hydrogen or synthetic fuels, including PEC systems, this evolution is quite significant. Rather than relying on short-term spot-market electricity or intermittent generation with uncertain supply, project developers can now structure long-term PPAs or CfD-style agreements with renewable-energy producers or aggregators. This provides stability: renewable supply, price, and temporal/locational matching, which helps meet RFNBO compliance criteria (temporal/geographic correlation) and improves economic predictability.

These market reforms yield several benefits:

- ✓ **Reduced price volatility** by locking in long-term electricity supply at predictable costs, renewable-fuel projects can model revenue, cost, and payback more reliably.
- ✓ **Compliance with RFNBO rules**. Long-term PPAs or CfDs with new renewable generation help satisfy additionality and temporal/geographical correlation requirements.
- ✓ **Easier integration for intermittent energy systems** for solar-driven PEC or hybrid PV-PV + PEC systems, direct coupling or ‘behind-the-meter’ renewables plus storage becomes more viable and bankable.

At the same time, significant challenges remain:

- ✓ **Permitting and grid access**. Building dedicated renewable generation, grid connections, and storage remains a bureaucratic and time-consuming process. In some Member States, delays in permitting and grid reinforcement may undermine project timelines or cost competitiveness.
- ✓ **Complexity of certification and documentation**. Even with long-term contracts, producers must document production times, electricity sourcing, and

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[18] https://energy.ec.europa.eu/news/hydrogen-mechanism-commission-launches-its-first-call-interest-connect-buyers-and-suppliers-2025-11-12_en
[19] https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen/european-hydrogen-bank/mechanism-support-market-development-hydrogen_en
[20] https://commission.europa.eu/topics/competitiveness/clean-industrial-deal_en

ensure that supply meets 'new capacity' requirements. This adds administrative overhead and cost.

- ✓ **Uncertainty about long-term regulatory stability**. While the reforms are underway, not all Member States have fully implemented them. Compliance and market design may vary across countries, making cross-border or multi-site projects more complex.

3.4 State-Aid Evolution: Clean Industrial Deal and CISAF

A third major shift in the policy environment relates to state-aid rules and industrial decarbonisation support frameworks. Recognising that large-scale clean-tech deployment requires substantial investment and potentially prolonged periods before profitability, the European Commission has updated state-aid policy to better accommodate clean-energy industrial projects. This is embodied in the Clean Industrial Deal (CID)[21] and its accompanying state-aid instrument, the Clean Industrial State Aid Framework (CISAF)[22], adopted on 25 June 2025.

CISAF enables Member States to grant aid for:

- ✓ Rolling out clean energy (e.g., renewables, grid and storage)
- ✓ Lowering electricity costs for energy-intensive users
- ✓ Facilitating industrial decarbonisation (e.g., hydrogen, synthetic fuels, low-carbon processes)
- ✓ Ensuring sufficient manufacturing capacity in clean technologies
- ✓ De-risking private investments (e.g., via grants, guaranteed loans, interest subsidies, tax incentives)

In other words, CISAF offers a broad framework that allows governments to support demonstrators, pioneering manufacturing lines, pilot plants, and early commercial deployment of clean processes. Precisely the kind of investments needed for advanced renewable-fuel technologies like PEC-derived hydrogen or methanol.

The CID explicitly identifies energy-intensive industries, such as chemicals, steel, cement and refining, as priority sectors for support. The policy recognises that these sectors face structural challenges: high energy costs, global competition, and complex infrastructure requirements. By offering state aid, transitional support and favourable financing conditions, CISAF lowers the financial barrier for early adopters of clean technologies.

For a project like PHOTOSINT, which seeks to integrate a novel solar-to-fuel pathway into chemical or industrial applications (e.g., methanol as fuel/feedstock, hydrogen for processes or energy), this represents a major opportunity. National or regional authorities in the partner countries may, under CISAF, provide co-funding, preferential borrowing conditions, or subsidised electricity costs for pilot and demonstration plants. This aligns well with wider EU aims to build a competitive clean-tech manufacturing base, reduce dependence on fossil inputs, and foster circular economy practices.

Previously, state-aid programs for clean technologies were often temporary or ad-hoc, such as under the TCTF (Temporary Crisis and Transition Framework)[23]. CISAF replaces TCTF and creates a more stable, long-term system (valid until at least 2030).

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[21] https://commission.europa.eu/topics/competitiveness/clean-industrial-deal_en
[22] https://competition-policy.ec.europa.eu/about/contribution-clean-just-and-competitive-transition/clean-industrial-deal-state-aid-framework-cisaf_en
[23] https://competition-policy.ec.europa.eu/state-aid/legislation/temporary-crisis-and-transition-framework_en

This stability lowers regulatory risk and boosts investor confidence, which is essential for capital-heavy and long-term projects like PEC-based fuel production or clean chemical manufacturing.

3.5 Energy Security, Industrial Competitiveness and Resilience

Since 2022, EU climate and energy policy has become increasingly linked with concerns over energy security, domestic supply chains, and industrial competitiveness. The shock of energy price spikes and supply disruptions, initially caused by geopolitical events, has strengthened political support for developing domestic renewable energy and low-carbon fuel production. Consequently, policy tools now serve a dual purpose: decarbonization and energy sovereignty or resilience.

This change is evident in several areas:

- ✓ The EU's broader industrial strategy emphasizes the importance of keeping clean-tech manufacturing (such as PV, batteries, electrolysers, and synthetic-fuel plants) within Europe to avoid dependence on external suppliers. The CID explicitly addresses this strategic competitiveness.
- ✓ There is an expanding focus on circular economy and domestic value chains: using CO_2 as input (e.g., for methanol) aligns with recyclability and carbon-circularity ambitions, which are increasingly highlighted in EU policy and industrial decarbonisation strategies.
- ✓ The establishment of new market-making instruments such as the EHB aims to build an integrated European hydrogen and renewable-fuels market, reducing dependency on imports and increasing supply-chain resilience. The 2025 launch of the Hydrogen Mechanism (under the EHB) aims to improve transparency by connecting suppliers and buyers of renewable/low-carbon hydrogen and derivatives (ammonia, methanol, electro-synthetic fuels).
- ✓ The policy rhetoric has shifted. Clean energy and fuel deployment is no longer merely an environmental or climate goal, but a strategic industrial and geopolitical priority. The 2025 CID explicitly frames decarbonisation as essential for the competitiveness of European industry in global markets.

For projects such as PHOTOSINT that aim at solar-driven fuel production and industrial deployment, this means that political conditions are more favourable than ever. Public support, in the form of subsidies, state aid, procurement contracts, preferential electricity or financing, is increasingly framed as a strategic investment in European industry, rather than a benevolent subsidy or experimental incentive.

4. IMPLICATIONS OF THE CURRENT POLICY LANDSCAPE IN ADVANCED RENEWABLE-FUEL AND PEC-BASED PROJECTS

For a project such as PHOTOSINT, the 2025 policy landscape presents significant opportunities, but also exacting requirements. It is no longer sufficient to demonstrate that a PEC system can produce hydrogen or methanol at a lab scale. To be eligible for market premiums, auctions, off-take agreements or state aid, the entire production chain must meet RFNBO criteria, from renewable electricity sourcing to lifecycle emissions savings.

In practice, a potential follow-up PHOTOSINT project should model and plan for:

- ✓ On-site renewable electricity generation (e.g., dedicated PV arrays) used exclusively for PEC to ensure additionality and correlation.
- ✓ Long-term PPAs or CfDs with newly built renewables, complying with RFNBO supply criteria.
- ✓ Comprehensive LCA tracking, including PEC component production (semiconductors, catalysts), construction, operation, maintenance, fuel synthesis, and distribution (H_2 or methanol).

Thanks to the EHB and CISAF, PHOTOSINT can extend beyond demonstration, planning for early commercial deployment. The Hydrogen Bank's fixed-premium model makes a viable business case if hydrogen or methanol can be produced cost-competitively and certified as renewable. Simultaneously, national and state aid schemes (via CISAF) could offer co-funding, subsidized electricity, or reduced financing costs, crucial for capital-heavy PEC-to-fuel systems.

Given electricity market reforms, leveraging long-term PPAs, CfD-style contracts, or dedicated, co-located renewables with storage can secure a stable, compliant power supply. Where feasible, on-site PV coupled with PEC offers the simplest compliance path. Otherwise, hybrid approaches combining grid-sourced renewables (via long-term contracts) and on-site generation can balance cost, availability, and compliance.

Because of solar's intermittent and seasonal variability, incorporating energy storage or hybrid systems (such as batteries, hydrogen buffers, or methanol storage) can stabilize supply and enhance predictability, boosting economic viability and certification quality.

Targeting energy-intensive industries like chemicals, metals, steel, and cement aligns with the CID. Since PHOTOSINT integrates chemical industry outputs (methanol, hydrogen as energy vectors or feedstock), a continuation project can argue for priority support under national and state aid programs. By positioning its outputs as renewable fuels, components of a circular economy (CO_2-derived methanol), energy security through domestic fuel supply, and industrial competitiveness, reducing reliance on fossil imports, it can meet various policy goals, increasing chances of support, off-take agreements, and market adoption.

Stakeholders, including chemical firms, energy producers, and government ministries, are increasingly open to solutions combining renewables, process energy substitution, and resilience. This political momentum could lead to more favorable regulation, simplified permits, or preferred off-take terms.

With more regulation and competition for deployment funding, PHOTOSINT related projects should be prepared for increased administrative complexity: certification, long-term record-keeping, compliance monitoring, supply-chain traceability, and regulatory reporting. Scaling up will require not only technical design but also comprehensive business, legal, and supply-chain documentation.

4.1 Risks, Challenges and Uncertainties

While the evolving policy landscape offers many opportunities, several risks and uncertainties remain:

- ✓ **Regulatory implementation differs across Member States**. Not all EU countries have equally streamlined permitting, grid access, or renewable energy deployment processes. National laws, administrative capacity, and grid limitations may cause delays for projects, especially those involving new renewables and grid connections.
- ✓ **Cost pressures from RFNBO compliance**. Meeting added criteria such as additionality, correlation, and lifecycle standards, particularly for new renewables, energy storage, or on-site generation, could significantly increase capital costs. A recent modeling study suggests strict compliance requirements might raise system costs by tens of billions of euros through 2048[24]. For PEC-based projects, which may not yet be cost-effective, this could challenge economic viability until further reductions in technology costs or policy support occur.
- ✓ **Technology bias and competition with established electrolysis-based routes**. Funding and auctions might favor mature electrolyzer + PtX technologies with well-known performance, capacity, and risk profiles. Less proven, innovative technologies (e.g., solar PEC) may struggle to compete unless they adopt hybrid designs, co-locate with renewables, or use conservative output estimates. This could limit disruptive adoption.
- ✓ **Administrative burden and certification costs**. The requirements for documentation, accounting, certification, lifecycle reporting, and compliance are substantial. For a multi-partner, multinational consortium like PHOTOSINT, coordinating these efforts across different EU Member States, each with its own regulatory and procedural environment, may be complex and resource-intensive.
- ✓ **Market and off-take risk persists**. Even with subsidies, the hydrogen and synthetic fuels markets are still developing. Demand remains uncertain, and securing off-take agreements with industrial users or fuel buyers may take time. Regulatory compliance alone does not ensure commercial viability or steady demand.
- ✓ **Supply chain and manufacturing issues**. Scaling PEC-based systems requires producing catalysts, semiconductor materials (possibly based on earth abundant elements), reactors, PV cells, and related infrastructure. As EU clean-tech sectors expand, supply chain constraints, including raw materials, equipment, and labor, might slow deployment or increase costs.

4.2 Strategic Recommendations for the PHOTOSINT project

Given the transformed policy context, the following strategic recommendations are proposed for a potential PHOTOSINT follow-up project or similar projects aiming at industrial-scale renewable fuels via solar-driven PEC or related technologies:

1. **Adopt a ‘compliance-first’ design approach**. From the earliest project phases, design around RFNBO rules (additionality, correlation, lifecycle emissions), and develop solid documentation, accounting, and certification workflows.
2. **Prioritize hybrid or co-located renewable supply setups**. On-site PV (or other renewables) combined with storage, or long-term PPAs / CfD contracts with

[24] https://arxiv.org/abs/2502.10859

newly built renewables, to meet electricity sourcing criteria while ensuring reliable supply and predictable costs.

3. **Prepare for deployment funding and state aid applications**. Plan the shift from R&I demonstration to commercial-scale deployment, including business models tied to auctions or national/state aid under CISAF, and align pilot outputs with eligibility criteria (certification, capacity thresholds, scalability).
4. **Engage with national authorities, hydrogen valleys, and industrial cluster stakeholders**. Since industrial decarbonization and clean-tech manufacturing are now strategic priorities, early engagement with policymakers, industrial clusters, and potential off-take partners (chemical companies and energy users) can secure support, favorable terms, or partnership arrangements.
5. **Invest in lifecycle analysis, supply chain mapping, and documentation infrastructure**. To meet certification and regulatory demands, assign higher efforts for LCA, materials tracking, compliance documentation, reporting, and audit readiness.
6. **Implement a phased scale-up strategy with regular reviews**. Start with small, well-documented pilots; assess economic, technical, and regulatory performance; then expand progressively, incorporating lessons learned and aligning with upcoming auction/state aid windows or market growth.
7. **Stay aware of alternative hydrogen / PtX routes**. Because deployment funding may favor mature electrolyzer-based solutions, PEC-based projects should position themselves carefully as complementary (e.g., hybrid or distributed production) or as niche solutions where solar-to-fuel integration offers particular advantages (e.g., remote or wastewater-driven sites, chemical plants needing direct renewable process energy).

5. POLICY RECOMMENDATIONS BASED ON PHOTOSINT OUTCOMES

To accelerate Europe's competitiveness and resilience in advanced renewable fuel technologies, a targeted set of policy actions is required. The following recommendations aim to address regulatory ambiguities, strengthen economic feasibility, support industrial integration, and facilitate the demonstration and scale-up of PEC systems and other innovative solar-driven conversion technologies. Besides, a policy brief for accelerating solar-driven hydrogen and methanol production in Europe is proposed.

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1. Strengthening the Regulatory Framework for Emerging Solar-Driven Fuel Technologies

Across the EU, policy frameworks dealing with renewable hydrogen and solar-based chemical production tend to be oriented towards electrolysis and biomass pathways. PEC technologies, despite their strong long-term potential for high solar-to-fuel efficiency, resource use efficiency, and decentralised operation, are rarely referenced in strategies, certification schemes or permitting frameworks.

Therefore, policymakers should ensure that:

1.1 PEC and solar-to-fuel technologies are explicitly recognised in EU and national legislation

The Renewable Energy Directive, national hydrogen strategies, and industrial decarbonisation plans should include PEC technologies as eligible renewable fuel production routes. This recognition would remove potential ambiguity when evaluating their status under RFNBO rules, sustainability criteria, or national incentive schemes.

1.2 Certification frameworks evolve to accommodate non-electrolytic pathways

The current RFNBO Delegated Acts are primarily designed around electrolyser-based hydrogen production powered by renewable electricity. PEC systems may operate using integrated light capture without grid electricity or PPAs. To avoid excluding such technologies, certification guidelines should include tailored provisions for systems that generate fuel directly from solar energy without relying on time-based correlation rules or additionality requirements designed for electrolysis.

1.3 Harmonised standards for PEC device testing, performance reporting and durability assessment are developed

Standardisation bodies should work with research consortia to develop European standards for PEC cells, catalysts and integrated reactors. Consistent data formats will both reduce uncertainty among regulators and help financial institutions evaluate the bankability of emerging solar-fuel production technologies.

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2. Enhancing Funding Mechanisms for Pilot Plants and Early Industrial Demonstrations

The transition from laboratory innovation to industrial deployment remains the most significant barrier for promising PEC technologies. While Horizon Europe provides strong support for research and development, support for scaling up novel solar-driven systems remains limited.

2.1 The European Hydrogen Bank and similar auction-based schemes should create dedicated windows for emerging renewable hydrogen technologies

The current auctions are oriented mainly towards mature electrolysis-based production. Establishing a 'Technology Innovation Window' for early-stage renewable hydrogen routes would allow PEC and hybrid PEC–PV systems to compete for support on a level playing field. This could adopt a non-price-only tender model, rewarding innovation, sustainability, reduced critical raw material usage, and potential for future cost reduction.

2.2 The CISAF should explicitly support pre-commercial solar-fuel demonstrators

Member States could apply CISAF provisions to fund PEC pilot sites at industrial facilities, especially where direct integration with wastewater streams, CO_2 capture units or chemical processes is possible. Such support should include CAPEX and OPEX assistance, as well as guarantees for longer-term off-take.

2.3 Strengthened regional instruments for industrial testbeds

Some Member States already run industrial testbed programmes through regional development agencies. These should be expanded to include solar-to-fuel pilot installations, enabling chemical companies, agricultural facilities or remote industrial sites to host real-world PEC systems under fully monitored conditions.

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3. Supporting Industrial Integration and Cross-Sector Collaboration

A key advantage of PEC systems lies in their potential for distributed production and their compatibility with locations where both sunlight and suitable feedstocks (wastewater, low-grade CO_2 or process effluents) are available. However, without strategic coordination, industrial uptake is likely to be slow.

3.1 Integrated energy–water–chemicals planning should be encouraged at national and regional levels

PEC systems rely on water treatment and CO_2 capture interfaces. Governments should promote cross-sectoral roadmaps linking hydrogen strategies, circular water policies and industrial carbon management systems. This will ensure that regulatory frameworks do not silo PEC solutions into the narrower 'hydrogen' domain, which may restrict deployment in locations where their multifunctional benefits are greatest.

3.2 Incentivising industrial symbiosis models for on-site renewable fuel production

Tax incentives, fast-track permitting, and public–private partnership models should reward industrial sites that integrate renewable fuel production directly into their processes. Sectors such as fertiliser production, glass manufacturing, ceramics, and remote agriculture would benefit from on-site solar-driven hydrogen or methanol production.

3.3 Creating support schemes for retrofitting industrial facilities with solar-driven fuel systems

The EU and Member States should establish grant-based programmes to assess the technical and economic feasibility of integrating PEC systems into existing chemical and manufacturing facilities. This should include feasibility studies, engineering design, environmental permitting, and workforce training.

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4. Facilitating Market Uptake Through Clear Demand Signals and Long-Term Policy Stability

While technological progress is necessary, the long-term viability of PEC fuels will depend on predictable demand, appropriate pricing signals, and robust market frameworks.

4.1 Strengthening renewable hydrogen and e-fuel demand mandates

RED III introduces RFNBO quotas for industry and transport, but their implementation varies across Member States. Ensuring consistent and ambitious national implementation – with explicit recognition of solar-derived fuels – would provide a stable market for early adopters of PEC technologies.

4.2 Long-term carbon pricing and carbon contracts for difference (CCfDs)

Carbon pricing under the EU Emissions Trading System provides an important signal, but remains volatile[25]. Long-term CCfDs would guarantee a stable floor price for renewable fuel producers[26], including those using innovative solar-driven technologies. This would provide investment certainty for PEC-based plants, particularly during early commercialisation.

4.3 Enhancing green public procurement

Governments should include renewable hydrogen and solar-derived fuels in public procurement criteria for public transport, municipal services, and public industrial projects. Such measures would create early niche markets where innovative technologies could demonstrate competitive performance.

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5. Supporting Skills, Manufacturing Capacity and European Industrial Leadership

A long-term deployment strategy for PEC systems requires not only technological readiness but also a skilled workforce and resilient supply chains.

5.1 Developing training programmes for PEC manufacturing, operation and maintenance

Vocational and academic institutions should work with industry to create curricula addressing catalyst production, PEC module assembly, systems engineering and safety protocols.

5.2 Supporting EU-based manufacturing of PEC components

The Net-Zero Industry Act[27] already prioritises renewable hydrogen equipment, but should expand its scope to solar-fuel conversion devices, semiconductor materials and integrated PEC modules. This would position Europe as a leader in next-generation solar fuels, reducing dependency on non-EU supply chains.

5.3 Ensuring sustainable sourcing and recycling pathways for PEC materials

Policies should promote circularity in catalysts, absorbers and cell components, incentivising recycling schemes and low-impact design. This aligns with the EU's sustainability objectives and strengthens the case for PEC adoption.

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6. Conclusion

The PHOTOSINT project illustrates the transformative potential of solar-driven fuel production for the European chemical and energy sectors. Yet, without targeted regulatory adaptation, dedicated demonstration funding, and strong cross-sectoral coordination, Europe risks under-utilising a technology area where it currently holds global scientific leadership. By modernising certification frameworks, incentivising industrial integration, and creating a favourable investment environment for emerging solar-fuel technologies, policymakers can help ensure that PEC systems evolve from research prototypes into commercially viable, climate-positive solutions that contribute meaningfully to Europe's long-term energy security and industrial competitiveness.

[25] https://economy-finance.ec.europa.eu/trends-carbon-intensity-and-macroeconomic-role-eu-emissions-trading-system_en
[26] https://www.catf.us/2022/08/why-are-carbon-contracts-difference-gaining-popularity-europe/
[27] https://commission.europa.eu/topics/competitiveness/green-deal-industrial-plan/net-zero-industry-act_en

POLICY BRIEF

Accelerating Solar-Driven Hydrogen and Methanol Production in Europe: Policy Recommendations from the PHOTOSINT Project

This policy brief proposes a targeted set of recommendations to support the industrial uptake of photoelectrochemical (PEC) technologies for the direct solar-driven production of renewable hydrogen and methanol. Derived from the Horizon Europe project PHOTOSINT, the recommendations aim to strengthen the regulatory, financial and industrial framework required for advanced solar-fuel technologies to reach commercial deployment.

1. Context and Rationale

Europe's energy-intensive industries face increasing pressure to reduce greenhouse gas emissions while strengthening energy security and competitiveness. The PHOTOSINT project demonstrates how PEC cells and integrated solar-driven processes can convert sunlight, wastewater and captured CO_2 into hydrogen and methanol at high efficiencies.

Despite strong policy support for renewable hydrogen, the current regulatory environment remains electrolysis-centric, and emerging solar-to-fuel technologies are insufficiently recognised in EU legislation, certification schemes and industrial support instruments.

This brief identifies key levers for policymakers to enable Europe to capture leadership in next-generation renewable fuel technologies.

2. Key Policy Challenges

- ✓ **Regulatory ambiguity:** PEC systems are not explicitly included in the RED III framework, national hydrogen strategies, or RFNBO certification methodologies.
- ✓ **Funding gaps:** Existing public funding largely focuses on mature electrolysers, leaving innovative solar-fuel technologies without dedicated deployment support.
- ✓ **Industrial integration barriers:** Permitting, sectoral silos and limited cross-industry coordination hinder the uptake of on-site solar-fuel production.
- ✓ **Market uncertainty:** Variable carbon pricing and slow implementation of RFNBO quotas affect investor confidence.
- ✓ **Skills and manufacturing gaps:** Europe currently lacks dedicated training programmes and manufacturing capacity for PEC components.

3. Policy Recommendations

A. Establish a Clear Regulatory Basis for PEC Technologies

- Explicitly recognise PEC pathways in EU and national hydrogen legislation, RED III implementation guidance, and industrial decarbonisation plans.
- Adapt RFNBO certification rules to accommodate solar-driven fuel production that does not rely on renewable electricity sourcing, thus avoiding inappropriate additionality and correlation requirements.
- Develop harmonised standards for testing, performance metrics, lifetime assessment and safety protocols for PEC cells and integrated reactors.

B. Expand EU and Member State Funding to Support Demonstration and Scale-Up

- Create a dedicated innovation window within the European Hydrogen Bank to support early commercialisation of non-electrolytic hydrogen production routes, including PEC.
- Use the Clean Industrial State Aid Framework (CISAF) to co-fund PEC-based pilot plants, industrial demonstrators and retrofitting of industrial facilities.
- Establish regional industrial testbeds where PEC systems can be validated under real operational conditions, supporting cross-sector collaboration.

C. Facilitate Industrial Integration through Cross-Sector Coordination

- Promote integrated energy–water–carbon planning, linking hydrogen strategies with wastewater reuse and carbon management policies.
- Incentivise industrial symbiosis models where PEC systems utilise existing industrial effluents (wastewater, CO_2) to produce on-site renewable fuels.
- Support retrofit feasibility studies for deploying PEC technologies in chemical, glass, fertiliser, ceramics and remote industrial facilities.

D. Strengthen Market Signals and Investment Certainty

- Ensure ambitious and consistent implementation of RFNBO quotas across Member States, with explicit eligibility for solar-derived hydrogen and methanol.
- Deploy carbon contracts for difference (CCfDs) to guarantee long-term revenue stability for early PEC-based fuel producers.
- Expand green public procurement to include renewable hydrogen and e-fuels from innovative production routes, creating early niche markets.

E. Build European Capability in Skills, Manufacturing and Sustainable Supply Chains

- Introduce training programmes on PEC materials, device integration, systems engineering and safety.
- Expand the scope of the Net-Zero Industry Act to include solar-fuel conversion technologies, supporting EU-based manufacturing of PEC components.
- Develop circularity standards and recycling frameworks for catalysts, membranes and semiconductor components used in PEC systems.

POLICY BRIEF

Accelerating Solar-Driven Hydrogen and Methanol Production in Europe: Policy Recommendations from the PHOTOSINT Project

4. Expected Impacts

Implementing these recommendations would:

- ✓ Accelerate the commercial readiness of PEC and artificial photosynthesis technologies.
- ✓ Strengthen European industrial leadership in next-generation solar fuels.
- ✓ Support the decarbonisation of hard-to-electrify industrial sectors.
- ✓ Enhance energy security through locally produced renewable hydrogen and methanol.
- ✓ Contribute directly to the objectives of RED III, REPowerEU, the European Green Deal, and the forthcoming Clean Industrial Deal.

5. Conclusion

The PHOTOSINT project demonstrates that PEC-based solar-fuel technologies hold significant potential to transform the European industrial energy landscape. However, without targeted policy action, Europe risks falling behind in a field where it currently possesses strong scientific expertise.

By modernising regulatory frameworks, expanding funding instruments, supporting industrial integration, strengthening market incentives and building strategic capabilities, European institutions and Member States can unlock the full potential of solar-driven renewable fuel technologies. These reforms would not only accelerate progress toward climate neutrality but also reinforce Europe’s industrial resilience and technological sovereignty in the global clean-energy transition.

7. CONCLUSIONS

The PHOTOSINT project aims to showcase PEC systems' potential in Europe's shift to renewable hydrogen, synthetic fuels, and climate-neutral processes. It develops materials, device designs, and system strategies for solar-driven hydrogen and methanol production, supplementing electrolysis and enabling distributed, low-carbon fuel. As Europe's climate, energy security, and industrial goals strengthen, technologies converting sunlight, wastewater, and CO_2 into clean energy become increasingly vital.

However, the progress of PHOTOSINT also illustrates that technological innovation alone is insufficient to guarantee industrial uptake. The period from 2023 to 2025 marked a decisive evolution in the EU's regulatory and policy landscape for renewable fuels, shifting from exploratory support to structured, deployment-focused frameworks. The adoption of RFNBO rules, the establishment of the EHB, the emergence of the Clean Industrial Deal and the wider reform of electricity-market design have created both opportunities and new compliance requirements for advanced renewable-fuel technologies. These developments frame the environment in which PEC systems must mature, be demonstrated and ultimately deployed. As such, the insights gained throughout PHOTOSINT highlight the importance of aligning technology development with a rapidly changing set of regulatory, economic and industrial expectations.

A key conclusion of this deliverable is that PEC-based solar-fuel production stands at a critical juncture. The technology aligns with several high-level EU objectives - decarbonisation of the chemical sector, increased production of renewable hydrogen, circular-carbon processes, strategic autonomy, and efficient resource use - but remains under-recognised in operational policy instruments and certification frameworks. For instance, the Renewable Energy Directive and its delegated acts were drafted with electrolysis as the assumed production route, leaving ambiguity over how PEC systems can demonstrate compliance with additionality, temporal correlation and lifecycle-emissions requirements. Without explicit recognition or adapted methodologies, PEC routes risk falling outside the regulatory definition of renewable hydrogen or renewable synthetic fuels, which would limit their eligibility for public support, market incentives and off-take agreements.

At the same time, the increasing maturity of deployment instruments such as the EHB and CISAF offers a window of opportunity for emerging technologies. The fixed-premium model of the Hydrogen Bank has demonstrated its capacity to stimulate renewable-hydrogen production, yet the current structure favours technologies at higher technology-readiness levels. PEC systems, still progressing through research and early demonstration stages, require tailored innovation windows or support mechanisms that recognise their long-term cost-reduction potential and ability to contribute to diversified hydrogen and methanol production. Similarly, the expanded possibilities under CISAF for state aid can enable Member States to co-fund pilot plants, testbeds and first-of-a-kind industrial units, helping projects such as PHOTOSINT bridge the gap between laboratory performance and industrial integration.

A second major conclusion is that industrial integration of PEC technologies will require close coordination between energy, water, chemical and circular-economy policies. One of the defining strengths of PEC systems is their capacity to utilise wastewater streams and captured CO_2, directly linking renewable-fuel production with industrial waste valorisation and water-resource management. This positioning places PEC technologies at the intersection of several policy domains, yet current regulatory frameworks tend to approach renewable hydrogen and e-fuels primarily through an energy-system lens. As a result, opportunities for cross-sectoral synergies - such as coupling PEC systems with industrial effluent streams, carbon-capture units or decentralised water-treatment facilities -remain underexploited. Future policy design should therefore move towards integrated planning approaches, encouraging industrial symbiosis models and reducing administrative or regulatory fragmentation.

Furthermore, the policy analysis carried out in this deliverable underscores the growing importance of lifecycle analysis, materials sustainability and supply-chain considerations. As PEC technologies begin to mature, policymakers and industry will increasingly expect clarity on the environmental impacts of materials used in catalysts, semiconductors and reactor components. Ensuring sustainable sourcing, recyclability, and the avoidance of critical raw materials will be essential for the long-term competitiveness and acceptability of PEC devices. Europe's broader industrial ambitions also open pathways for the future localisation of PEC component production, if supported through targeted programmes and appropriate market signals.

A third conclusion relates to market formation and demand certainty. PHOTOSINT's analysis shows that even highly innovative technologies with strong long-term potential face significant barriers when market frameworks are fragmented or immature. While the EU has introduced renewable-fuel quotas, RFNBO targets and hydrogen market coordination platforms, implementation varies across Member States, and long-term demand for renewable hydrogen and e-fuels remains partly uncertain. Stable and sufficiently ambitious demand-side measures such as coordinated RFNBO implementation, CfDs, and green public procurement will be essential to ensure that emerging technologies can access predictable markets during their early commercial phases. Without such measures, the risks associated with technology novelty and capital intensity may slow industrial uptake.

Finally, the deliverable concludes that PEC technologies, though still in early development, align remarkably well with the EU's long-term strategic orientation. They offer efficient use of solar energy, potential for low-cost deployment at scale, reduced dependence on grid electricity, and integration with circular resource flows. In an energy system undergoing rapid decentralisation, PEC systems may ultimately complement other hydrogen-production routes by enabling flexible, site-specific and low-impact solar-to-fuel conversion. As Europe seeks to strengthen its resilience against energy disruptions, diversify its clean-energy supply chains and maintain leadership in advanced energy technologies, innovations such as those developed in PHOTOSINT could play an increasingly valuable role.

In summary, the PHOTOSINT project highlights both the promise of PEC-based solar-fuel production and the regulatory evolution needed to unlock its full potential. The project has generated scientific insights, demonstrated prototype components and outlined pathways for future scaling. At the same time, its policy analysis emphasises the need for explicit recognition of PEC technologies in renewable-fuel legislation, adapted certification frameworks, tailored deployment support, coordinated cross-sectoral planning and stronger market signals. Addressing these areas will not only support PEC development but will also help ensure that Europe can fully exploit its scientific leadership in artificial photosynthesis and next-generation solar fuels.

Looking ahead, the conclusions of this deliverable suggest that continued collaboration between policymakers, researchers, industry actors and standardisation bodies will be essential. By integrating scientific innovation with coherent policy frameworks and well-designed deployment mechanisms, Europe can position PEC technologies as an important component of its clean-energy transition. This alignment will be vital to transforming PHOTOSINT's achievements into real-world applications, supporting industrial decarbonisation, improving energy independence and contributing meaningfully to the continent's path towards climate neutrality.