Global Status of PV module Recycling: Current status of PV Module Recycling in IEA PVPS Task 12 Countries

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IEA PVPS Task 12 – PV Sustainability

- The goal of Task 12 is *to foster international cooperation and knowledge sharing on the sustainable aspects of PV technology, emphasizing environmental and social factors*. Its mission is to provide essential information to stakeholders, enhancing consumer and policy-maker confidence in PV systems, and thereby accelerating the shift towards sustainable energy.

- Task 12 Subtasks
  - Circular Economy
  - Environmental Life Cycle Assessment (LCA)
  - Ecosystem-integrated PV
  - Other PV sustainability topics

IEA PVPS Task 12 – PV Sustainability

- Task 12 is operated jointly by the National Renewable Energy Laboratory (NREL) and TotalEnergies. Support from the United States' Department of Energy (DOE) and TotalEnergies are gratefully acknowledged.

- Participants: country and industry
  - Australia, Austria, Belgium, Canada, China, France, Germany, Italy, Japan, Spain, Sweden, Switzerland, the Netherlands, United Kingdom, United States
  - SolarPower Europe, First Solar, Jinko Solar, PV Cycle, TotalEnergies, SOREN

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IEA PVPS Task 12 – PV Sustainability

Subtask 1 Circular Economy	Subtask 2 Life Cycle Assessment	Subtask 3 Ecosystem-integrated PV
Global PV recycling status	5th and 6th Edition of LCA Methodology Guidelines	Biodiversity and management in different PV systems and soils in solar parks
Patent review of PV recycling methods	LCI data and report (2025 and 2027 update)	Field research methods for Agrivoltaic applications
PV circular economy status	Study and comparison life cycle indicators from commercial PV recycling pilots and plants	Agrivoltaics Action group Task 12 Contribution
Repair of PV-Panels	2nd edition Net Energy Analysis methodological guidelines	Environmental impacts of floating PV on coral reef: A Case Study in a French Polynesian Atoll
PV waste management in France	Report of LCA of PV recycling pathways in France	
Critical material demand scenarios for PV in the terawatt era	LCA of IBC PV modules	**Subtask 4 Other Sustainability Topics**
Status and Trends for PV recycling in China	LCA of high-altitude PV installations in alpine environments	Studying Public Acceptance of PV modules
	LCA modelling recommendations for emerging PV tandem technologies and preliminary results based on experimental lab-scale data	Expanded human health risk assessment for landfilling of CdTe PV

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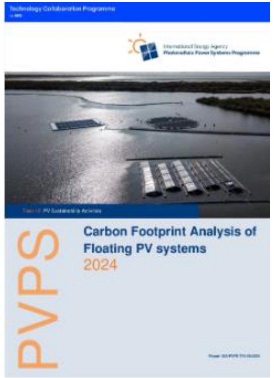
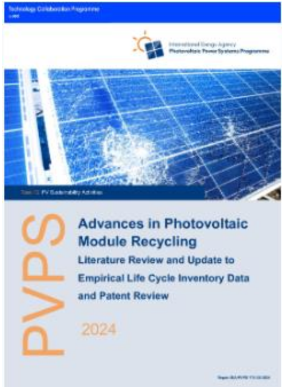
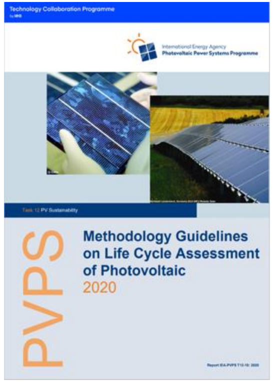
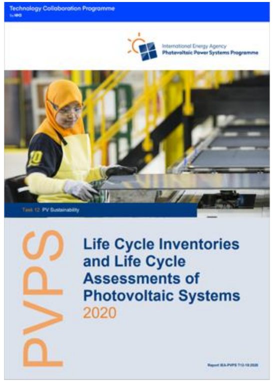
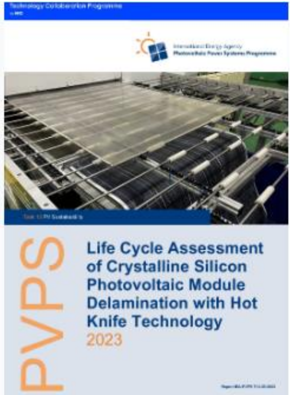
Selected Recent Publications

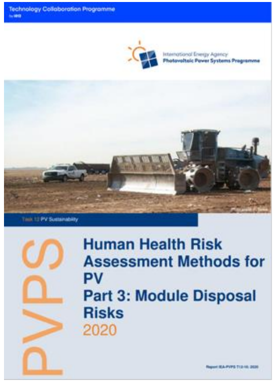


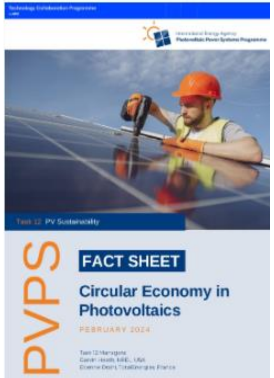


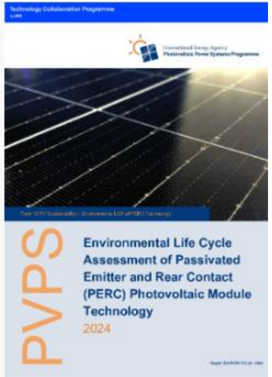


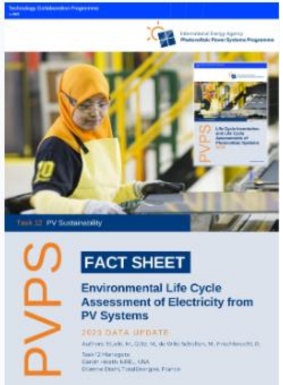


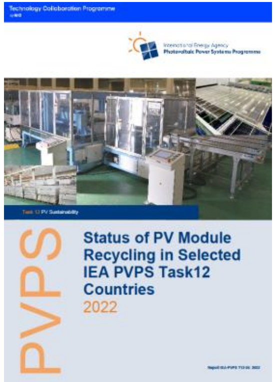












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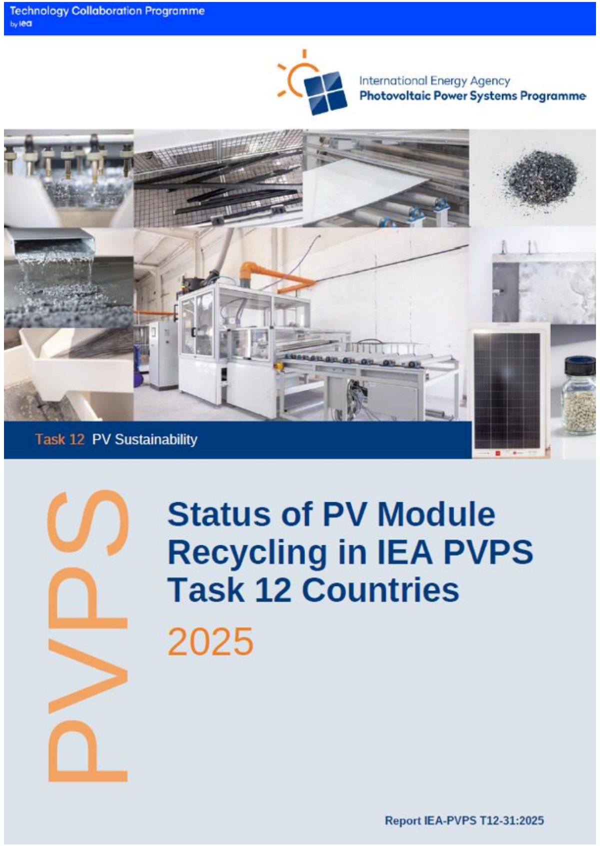
https://iea-pvps.org/research-tasks/pv-sustainability/

Report: Global status of PV module recycling (Sep. 2025)

- Status of photovoltaic module recycling
  - Europe: Germany, France, Italy, Spain, Belgium, the Netherlands, Austria, Sweden, Switzerland
  - Asia and the Pacific: Japan, South Korea, China, and Australia
  - North America: United States of America.
- Technology R&D for Photovoltaic module recycling
  - R&D projects in Europe
  - R&D projects in Asia and the Pacific
- Editor: Keiichi KOMOTO
- Authors/contributors: Task12 members



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Status of PV module recycling in IEA PVPS Task12 countries

Status of PV module recycling

- The amount of PV module waste is increasing, relevant regulations have become or are likely to become effective in other regions, and new facilities and equipment for PV module recycling—mainly for delamination—are being operated.

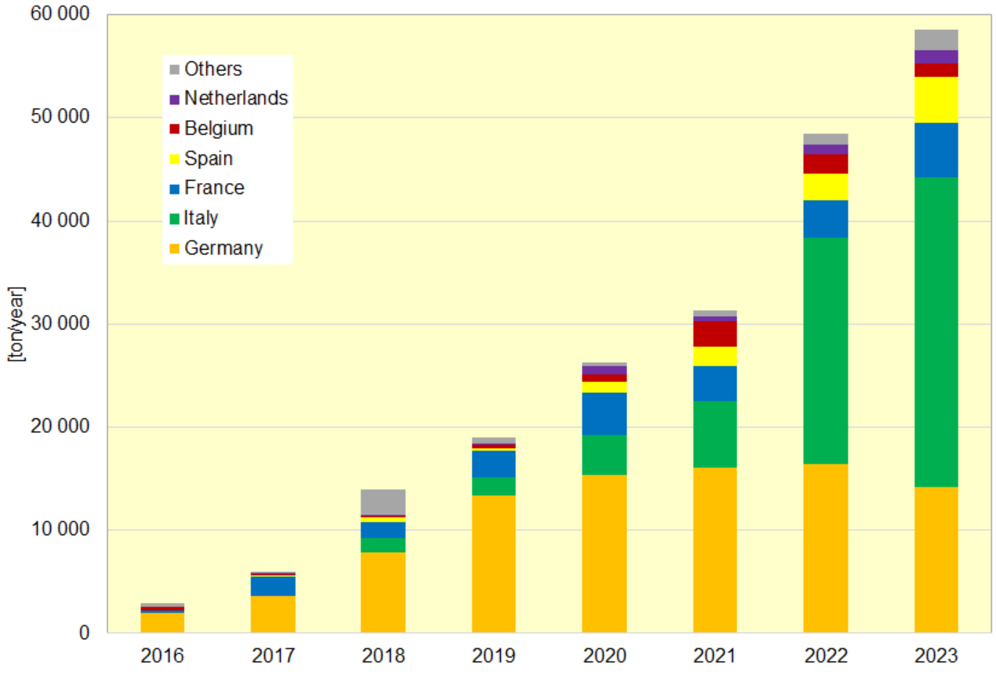
		Collected EOL PV modules [t/y] (by EUROSTAT)			No. of recyclers identified		Regulation/legislation	
		2018	2022	2023	2021/2022	2024/2025	2021/2022	2024/2025
Europe		13 951	48 395	58 504	-	-		
	Germany	7 865	16 430	14 186	2	6		
	France	1 555	3 582	5 272	3	3 + 1		
	Italy	1 350	21 493	30 003	0	2		
	Spain	462	2 603	4 551	0	7	WEEE Directive	
	Belgium	168	1 855	1 212		3		
	Netherlands	131	1 035	1 381		2		
	Austria	8	12	62	No survey	4		
	Sweden	-	-	-		3		
	Switzerland	-	-	-		0	No survey	

Ref.) K. Komoto, et al: IEA PVPS Task12: of PV module recycling in IEA PVPS Task12 countries, Report IEA-PVPS T12-31:2025 (modified on 5 Nov. 2025: added data in 2023)

Status of PV module recycling in IEA PVPS Task12 countries

PV module waste collected under WEEE in Europe

- The amount of collected EOL PV modules are growing to several times in some years. For example, in Europe, 58 504 tons of PV module waste were collected in 2023, and ones were 13 951 tons in 2018 and 48 395 tons in 2022, according to the Eurostat statistics.



Ref.) Eurostat statistics

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Status of PV module recycling in IEA PVPS Task12 countries

Status of PV module recycling

- A few years ago (2020/2021), although the WEEE Directive in Europe has come into force in the market since the 2010s, specific regulations for PV were not yet introduced in other countries. Since then, in South Korea, a PV EPR regulation has been enforced starting in 2023, and relevant political deliberations are being implemented in Japan, Australia, and the United States.

	Collected EOL PV modules [t/y]		No. of recyclers identified		Specific regulation/legislation for PV EOL treatment (national level)	
	Previous	This time	2021/2022	2024/2025	2021/2022	2024/2025
Japan	6 300 (in 2020)	2 079 (in 2022)	29	42	No	Under discussion
South Korea	279 (in 2020)	688 (in 2023)	3	5	Under discussion	EPR since 2023
China	No data	No data	7	10	No	No
Australia	No data	No data	7	7	Under discussion	Expected in 2025
United States	No data	760 [MW]* (in 2022)	8	39	No	Under discussion

* Value shown is an NREL-modeled estimate of EOL crystalline-silicon modules. Collected EOL PV modules are not tracked in the U.S.

Ref.) K. Komoto, et al: IEA PVPS Task12: of PV module recycling in IEA PVPS Task12 countries, Report IEA-PVPS T12-31:2025

Trends in Technology R&D for PV Module Recycling

Changes in objectives and motivations for PV module recycling

		c-Si	Thin-film compound (CdTe and CIGS)
1990s		Recovery of Si wafers without breakage because the module cost was very high and was dominated by the cost of the Si cell.	Recovering hazardous materials such as Cd and Se because of environmental issues and recovering rare metals such as Te and In because of the potential resource constraint issue.
2000s	First half	In addition to Si wafers, recovering Ag because of high value, and recovering Pb because of environmental issues.	Recovering semiconductor metals/layers is a major objective, with the issue of resource constraint being less of a concern.
	Second half	Recovery of glass is also a major concern to increase the efficiency of resource utilization and to increase the recovery/recycling rate (weight %).	
2010s		Recovery of high-weight components, such as glass, at a lower cost is a major aim. However, low-weight valuable components can be recovered if economically justified. Recovering metals at a lower cost is likely to be a major concern.	Recovery of both high-weight components such as glass and low-weight semiconductor metals/layers at a lower cost is an innovation driver. In addition to increasing the recovery/recycling rates, the quality of the materials recovered is also an issue.
2020s		Recovering materials with high purity and high yield and circulating such materials as valuable resources are targets of recycling. Recycling shall be introduced as a part of the PV supply chain and be shifting towards enabling recycling of high-value metals rather than high-weight alone.	

Ref.) K. Komoto, et al: IEA PVPS Task12: of PV module recycling in IEA PVPS Task12 countries, Report IEA-PVPS T12-31:2025

Trends in PV module recycling technology R&D (c-Si)

<u>2010s</u>

Focusing on delamination

- High volume processing
  - Shredding/sorting
- Glass separation
  - Combustion/pyrolysis
  - Heated blade
    - Hot knife®
    - Separator, blade, diamond wire, etc.
  - Scraping, blasting, hammering, etc.
  - Waterjet

<u>2020s</u>

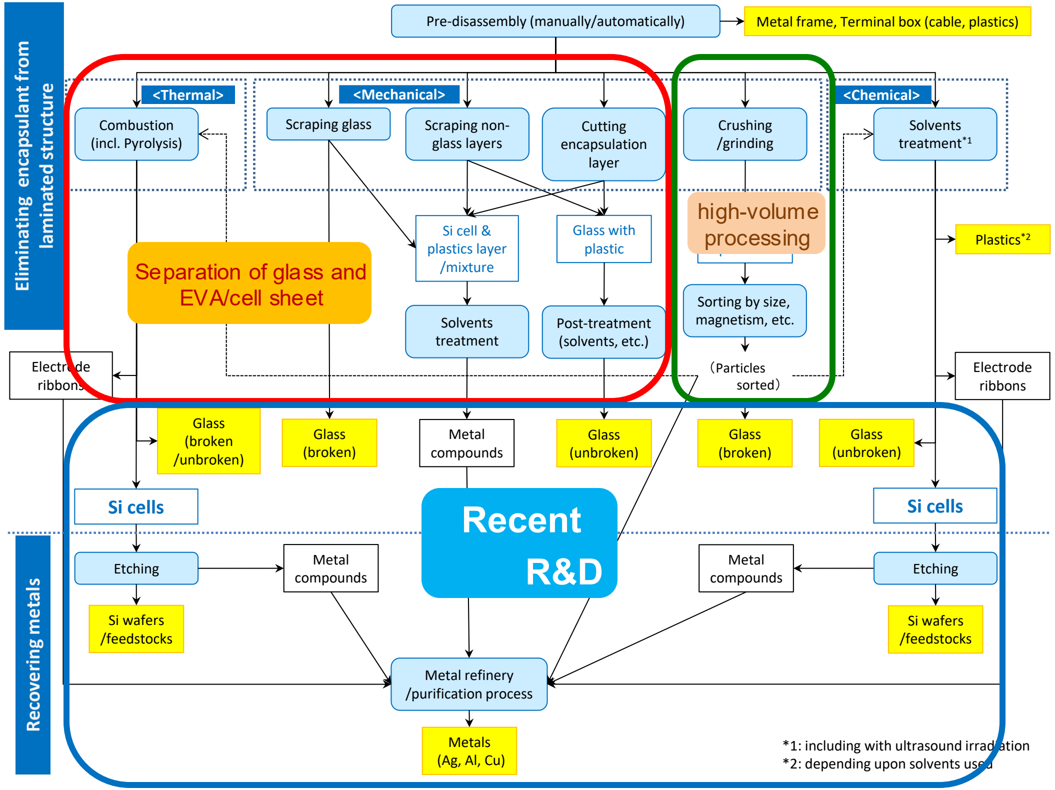
Metal recovery: Si, Ag, Cu, In

- High yield and high purity
- Environment friendly processes
  - Chemical solvents
  - Electrochemical approach

Valuable use of recovered materials

- Si to solar (or other industrials)
- PV glass to flat glass

Possible processes for c-Si PV module recycling



Ref.) K. Komoto, et al.: End of Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies, IEA-PVPS T12-10: 2018

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Trends in Technology R&D for PV Module Recycling

Target steps of R&D projects for PV module recycling

Region	Project / Organisation	Delamination	Metal recovery	Usage of materials
Europe	PHOTORAMA	Waterjet/Diamond wire	DES leaching → Electrowinning	Exploring end-usage
	EVERPV	Grinding/IR ramp → Recovery of glass, cell metals and polymers		Exploring end-usage
	RETRIEVE	Recovery of glass, cell metals and polymers		Exploring end-usage
	FORESi	Mechanical	Chemical	Si recycling
	ReSiLeX			Si recycling
	ICARUS			Si recycling
	QUASAR	Waterjet/Pyrolysis → chemical		Exploring end-usage
	APOLLO	Optical/Mechanical/Sonification/chemical		Exploring end-usage
Italy	IEMAP	Separator		Exploring end-usage
	Parsival	Thermal-mechanical-chemical	Hydrometallurgical with ultrasounds	
Spain	RESILIENS		Chemical	Si recycling
Austria	PVReValue	Waterjet/Mechanical/Thermal → Chemical		Exploring end-usage
Japan	Solar Frontier (NEDO)	Separator	Chemical	Exploring end-usage
	Tokuyama (NEDO)	Pyrolysis		Exploring end-usage
Australia	UNSW	Pyrolysis	Chemical	
	Swinburne Univ.		Pyrometallurgy	Si recycling

Ref.) K. Komoto, et al: IEA PVPS Task12: of PV module recycling in IEA PVPS Task12 countries, Report IEA-PVPS T12-31:2025

Trends in Technology R&D for PV Module Recycling

Target of recovered materials and expected use application of recovered materials

Region	Project / Organisation	Expected materials recovery	Target of recovery	Expected use application
Europe	PHOTORAMA	Glass, Al, Cu, Si, Ag, In (from HJT), polymer	Recovery rate : 98% (whole), 95% metal	n.a.
	EVERPV	Glass, Al, Cu, Si, Ag, EVA, PET/PVF	Glass: 100% (recovery rate) Ag: 99% (purity), EVA/PET: 95% (purity)	Glass: flat glass Polymer: to be explored
	RETRIEVE	Glass, Al, Cu, Si, Ag, polymer	Recovery rate : glass 99%, Si 98%, Ag 99%	Glass: PV glass, Al, Cu, Ag: non-ferrous metal, Polymer: synthesis gas
	FORESi	n.a.	Recovery rate: 95% (whole)	Si; SOG-Si (>15%)
	ReSiLeX	Si	n.a.	Si: SOG-SI, LiB anode material, Recycling of 97% of recovered Si
	ICARUS	Si (plus silica & graphite from manufacturing waste)	Recovery rate: 95% (whole)	SI: SOG-Si, liquid glass
	QUASAR	Glass, Al, Cu, Si, Ag, polymer	Recovery rate: Si 90%, Ag: 90%, polymer 90%	Glass: flat glass (float glass), Metals: PV cell/module
	APOLLO	Glass, Al, Cu, Si, Ag, polymer	Recovery rate: 93% (whole), Si purity: 6N	Glass: PV glass, Si: SOG-Si
Italy	IEMAP	Glass, Cu, Ag, polymer	n.a.	Ag: AgBr, Cu: CuC_2O_4
	Parsival	Glass, Al, Cu, Si, Ag	Recovery rate: 87% (whole)	-
Spain	RESILIENS	Si, other metals from Si cell	n.a.	Si: SOG-Si
Austria	PVReValue	Glass, Si, metals, polymer	Recovery rate: 95% (whole)	n.a.
Japan	Solar Frontier (NEDO)	Glass. Al, Cu, Si, Ag, polymer	Recovery rate: 80% (whole)	n.a.
	Tokuyama (NEDO)	Glass, Al, Cu, Si cell	Recovery rate: 80% (whole)	n.a.
Australia	UNSW	Glass, Al, Cu, Si, Ag	Recovery rate: 95% (whole)	n.a.
	Swinburne Univ.	Si, Ag	Si: 6N (purity), Ag: 90% (recovery rate)	Si: SOG-Si

Ref.) K. Komoto, et al: IEA PVPS Task12: of PV module recycling in IEA PVPS Task12 countries, Report IEA-PVPS T12-31:2025

Conclusions

- The EU has adopted the WEEE Directive for PV waste. In other parts of the world, legislative and regulatory frameworks for PV module waste are installed or in preparation. Regardless of whether there are PV-specific waste regulations, many companies are treating PV module waste for proper EOL management and recycling, and the number has increased since the last time IEA PVPS Task 12 surveyed three years ago.

- The current low volumes, limited recycling technologies, logistics challenges, and underdeveloped markets for recovered materials result in a high-cost, low-revenue scenario for PV module recycling today. Further improvement in the PV recycling capacity and technology is needed to meet future increased demand and to realize the goal of high-value, low-cost recycling. To improve economic aspects of PV module recycling, considering values of recovered materials such as critical minerals would be also necessary.

- PV module recycling technology is expanding from delamination to metal recovery as well as exploring more valuable markets for recovered materials. Enabling the use of recovered materials in new PV cells/modules and other high-value markets are ultimate targets, whereas impurities and additives remain issues to be solved. Recycled materials from PV module waste could play a significant role in material supply for PV module production and other industries.

www.iea-pvps.org

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IEA PVPS

A Brief Introduction of IEA PVPS Task17: PV and Transport

11 November 2025

Keiichi KOMOTO (IEA PVPS Task17 Manager, Mizuho Research & Technologies, Ltd, Japan)

IEA PVPS Task17: PV and Transport

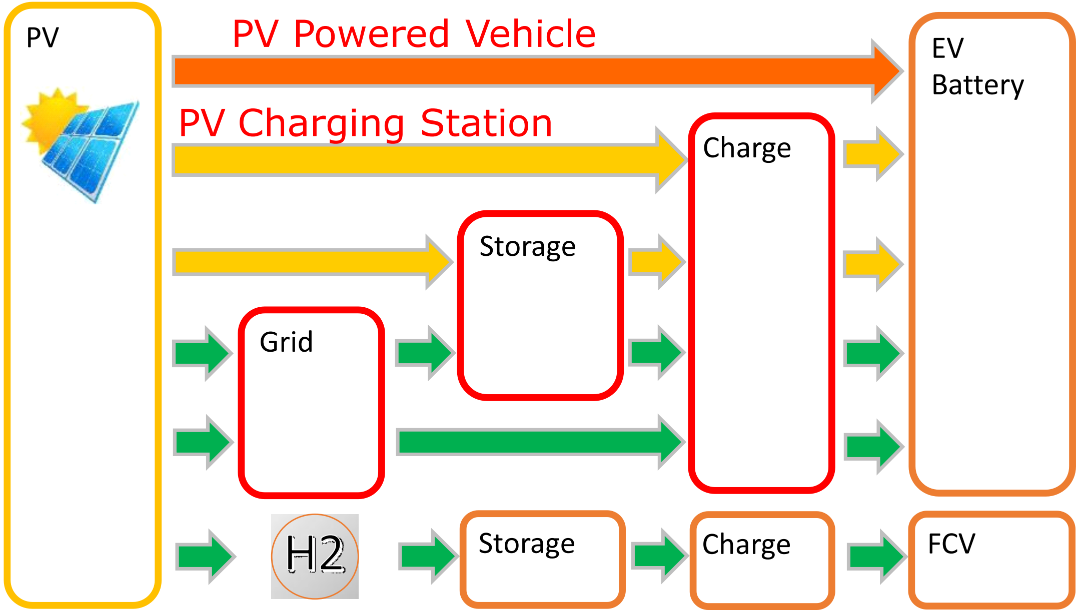

(https://www.nedo.go.jp/news/press/AA5_101150.html)

Goal

- Deploy PV usage in transport, which will contribute to reducing CO_2 emissions of the sector and enhancing PV market expansions

Participating countries

- Japan (Task manager), Australia, Belgium, China, France (co-Task manager), Germany, the Netherlands, Portugal, Spain and Switzerland



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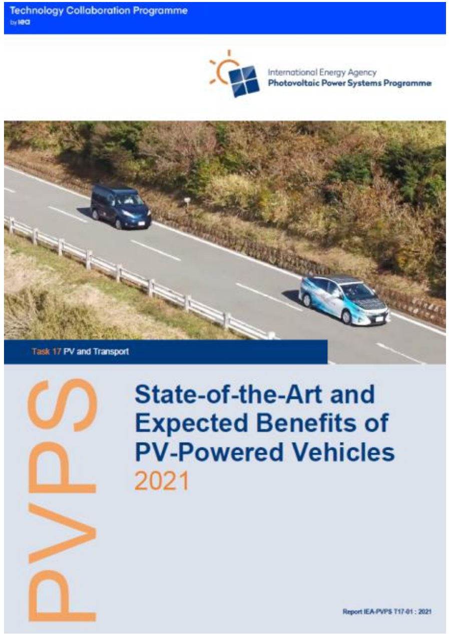
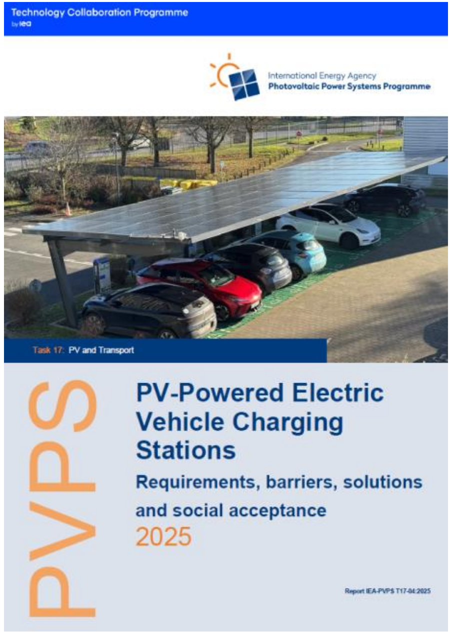
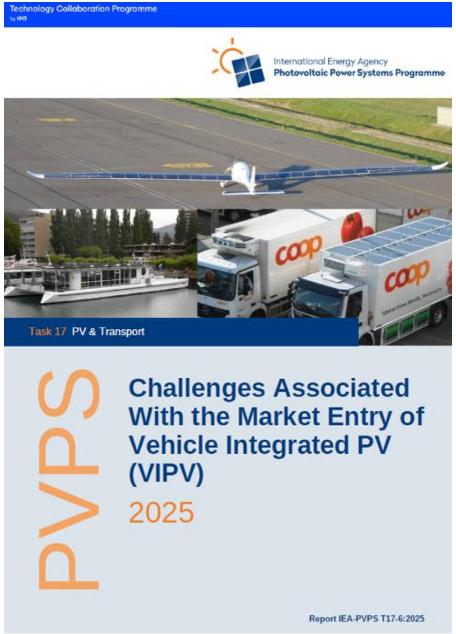
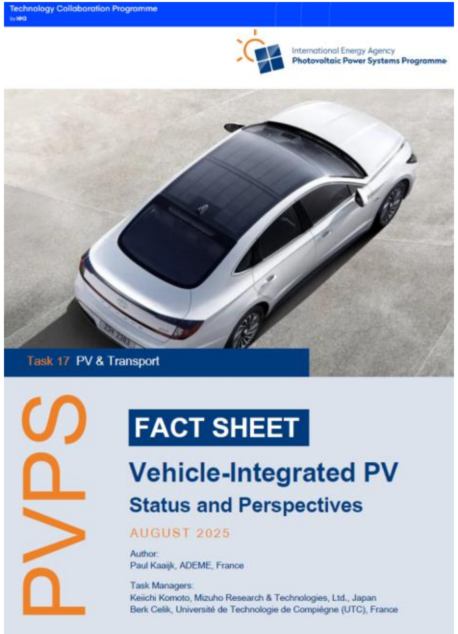
Examples of PVPS Task17 reports









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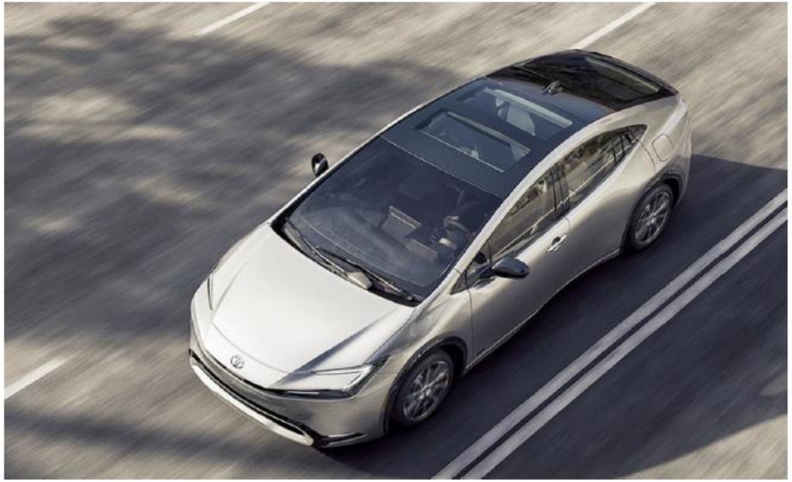
(https://iea-pvps.org/research-tasks/pv-for-transport/)

VIPV is already happening !



New workplan for 3 years, starting with Oct. 2025

- The work programme is organized into four technical subtasks. Dissemination activities to communication with stakeholders, in many different ways from workshops to scientific publication and reports, will be implemented within each Subtask.

  - **Subtask 1:** PV-powered vehicles (VIPV)
  - **Subtask 2:** PV-powered charging station (PVCS) and infrastructures
  - **Subtask 3:** Potential of PV integration into the transport
  - **Subtask 4:** Market analysis and business approaches for VIPV & PVCS (tentative)

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New workplan for PV-powered vehicles (VIPV)

1.1 Establishing/Validating Energy Potential

- Solar irradiance and VIPV potential measurement and modelling.
- Quantifying the potential for PV to supply energy to passenger vehicles.
- Impact of on board charging of the battery.

1.2 Studying Design and Technical Requirements

- Technical requirements for VIPV cells and modules.
- Design and study of solar powered light commercial vehicles (LCV) for post-delivery: monitoring of the running PV powered LCV.

1.3 Performing Environmental Impact Evaluation

- Global Life-Cycle Assessment (LCA) of VIPV: future generations of solar cells and modules technologies for VIPV applications.
- Design for recycling for VIPV.

1.4 Guidelines and Impact Evaluation of VIPV for Heavy Duty Vehicles

- Guideline for PV trucks.
- Impact evaluation of PV for heavy duty transport.
- Effect on battery lifetime for EV's.

1.5 Discussing Alternative Applications

- PV-powered flying airplanes, drones and balloons.

Ref.) https://pxpco.jp/news/

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