FRAUNHOFER CLUSTER OF EXCELLENCE CIRCULAR PLASTICS ECONOMY CCPE

LANDSCAPE ANALYSIS AND SURVEY: AI IN THE PLASTICS VALUE CHAIN BY 2030

Background report

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This report is the background report to the position paper "ARTIFICIAL INTELLIGENCE IN THE PLASTICS VALUE CHAIN BY 2030." In position papers, the Fraunhofer Cluster of Excellence Circular Plastics Economy CCPE addresses topics that are currently relevant to society, science and business. As CCPE researchers, we want to take a stand and contribute our opinion to current debates. At the same time, we want to show whether and how we can contribute to solving these challenges with scientifically sound data and facts. Our position papers are developed jointly by the staff of the Fraunhofer Cluster of Excellence Circular Plastics Economy CCPE – each position paper is the result of an opinion-forming process involving several institutes.

Fraunhofer CCPE combines the expertise of six institutes of the Fraunhofer Gesellschaft and works closely with other Fraunhofer institutes and industry partners. Together, we work on systemic, technical and social innovations, focusing on the entire life cycle of plastic products. Under the leadership of the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, the following research institutes have joined forces: Fraunhofer Institute for Applied Polymer Research IAP, Fraunhofer Institute for Chemical Technology ICT, the Fraunhofer Institute for Material Flow and Logistics IML, Fraunhofer Institute for Process Engineering and Packaging IVV and the Fraunhofer Institute for Structural Durability and System Reliability LBF. This report and the accompanying position paper "Artificial Intelligence in the Plastics Value Chain by 2030" were prepared by Fraunhofer UMSICHT and Fraunhofer IML.

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Abstract

The industrial use of plastics faces major challenges and, at the same time, new opportunities. In Germany and other European countries, less plastic is produced, processed and recycled [Plastics Europe-2025a]. At the same time, regulatory requirements (e.g., in the area of recycled material use and digital product passports) increase the pressure for greater recyclability and transparency [European Union-2024a; European Union-2024b]. The use of artificial intelligence (AI) influences many industries and also has an impact on the plastics industry. Much potential in processing and recycling remains untapped. This position paper summarizes the status and potential for the use of AI in the plastics value chain until 2030. An analysis of publicly available sources from industry associations, companies and policy makers, as well as a survey of 46 experts at Fraunhofer CCPE and project partners from the AI Hubs for Plastic Packaging's research projects "KIOptiPack" and "K^{3}I-Cycling," which were completed in 2025, show that:

- AI is already powerful in narrowly defined applications (quality testing, sorting, process control) and is seen as an important lever for efficiency, quality and recyclability by 2030.
- Intelligent cycles - i.e., end-to-end, data- and AI-supported material and product cycles from design to recyclate - are currently failing less due to the performance and reliability of new solutions than due to data, standards and economic business models.
- Respondents consider an *interoperable*, reliable *database* (material, process, quality and life cycle data) to be a key lever for economic and ecological optimization.
- The major areas of tension lie in data sharing (data availability vs. data hoarding), regulation (opportunities vs. overregulation), liability and the distribution of costs and benefits between companies.
- AI is an important lever, but not the only one: Design for recycling, product simplification, collection and recycling infrastructure and clear regulation remain equally crucial.

Based on these findings, Fraunhofer CCPE has identified the following priority areas for action by 2030:

1. Establishment and use of *interoperable data spaces* with *domain-specific data standards* and *ontologies* for plastics and their processes.
2. Development of hybrid, explainable and uncertainty-aware AI models for design, processing, collection, sorting and recycling.
3. The assessment and validation of economic efficiency and sustainability will determine how efficiently these technologies can be used in new fields of application.
4. It is essential to promote living labs or testbeds and end-to-end pilot projects that test data, process and decision chains from design to recyclate in practice and strengthen the innovative power of industry and research in Europe despite location disadvantages.
5. Systematic consideration of the environmental and energy effects of AI, as well as research into business models, *governance* and acceptance.
6. Targeted competence building (bridging skills) and clear distribution of roles between industry, research and politics.

This report addresses specific recommendations to industry, politics and research to realistically design intelligent cycles for plastics by 2030.

1 Introduction

Plastics are key materials in modern industrial and consumer goods. Every year, over 400 million tons of plastics are processed worldwide, but only a small proportion of post-consumer plastics are reused in products in the form of high-quality recyclates; quality losses often occur [Plastics Europe-2025c]. The transformation into a circular plastics economy is therefore an ecological and economically driven task and a key issue of industrial policy.

The **circular economy for plastics** refers to the transition from linear material flows to circular systems with high reuse, material and raw material recycling and closed material cycles wherever possible. Key elements include recycling-friendly design, single-type collection, efficient sorting and recycling processes, and the use and processing of recyclates in high-quality applications.

Artificial intelligence (AI) encompasses data-based processes – in particular machine learning and *deep learning* – that can recognize patterns in data, make predictions, support decisions or or automate (parts of) tasks, including through agent-based systems. AI methods are already being used in plastics value chain for image processing, process control, sorting and quality assurance.

The **Fraunhofer Cluster of Excellence Circular Plastics Economy CCPE** researches and strengthens the potential of innovative AI technologies along the plastics value chain through the cooperation of six Fraunhofer institutes. External perspectives from partners of the BMFTR-funded German "AI Hubs for Plastic Packaging" are integrated to identify practical solutions and existing obstacles. From Fraunhofer CCPE's perspective, AI can only unlock its potential for a circular plastics economy by 2030 if technical excellence is combined with a systemic perspective, open data structures and responsible research. CCPE sees AI as a key lever for closing material, process and data gaps. Priorities include *interoperable data spaces*, *domain-specific data standards* and hybrid, explainable AI models that are validated along real value chains. At the same time, the cluster acts as a neutral bridge builder between industry, research and politics to enable trustworthy *best practices*, shared learning and scalable solutions. The theses and recommendations formulated in the position paper reflect this stance. They aim at a European competitive, resource-efficient and socially accepted use of AI in plastics value chain, in which economic, ecological and social goals are explicitly balanced.

The **research question** is: "How can AI be used as a central lever in the plastics value chain to remedy material, process and data deficits, and what are the potentials and obstacles on this path until 2030?"

The position paper provides a research agenda and positions from the application-oriented and technology-driven perspective of Fraunhofer CCPE, supplemented by perspectives and opinions from the partners of the AI hubs for plastic packaging funded by the BMFTR until the end of 2025. The position paper is primarily aimed at industry players along the plastics value chain as well as research and politics. Technical terms that are not explained in the text are written *in italics* and are explained in the glossary.

2 Methodological framework and data basis

A multi-stage approach was chosen for the development of the position paper, triangulating public sources, AI-supported analyses and expert assessments within the thematic blocks shown in Fig. 01. The procedure is outlined step by step below.

Fig. 01: Topic blocks for generating theses for the position paper

Step 1 – Landscape analysis

First, the authors evaluated publicly available positions and activities of associations, companies, policy makers and cross-sector initiatives on the topic of AI and plastics. In particular, they recorded:

- goals and strategic positioning,
- current applications of AI (e.g., quality control, sorting, process optimization),
- maturity levels and gaps (data standards, infrastructures, scaling),
- drivers such as transparency and data requirements through regulation,

The results serve as a reference framework for AI-supported thesis formation.

Step 2 – AI-supported generation of statements and scenarios

In fall 2025, structured interviews were conducted with state-of-the-art large language models (e. g., GPT 5, Claude Sonnet 4.5 R) based on a CCPE catalogue of key questions. A total of 15 questions were asked on the topics described in the introduction. Prompt logic and dialogue were documented. The AI responses were not used as a source of facts, but were critically questioned and recorded (assumptions, risks, interactions) and compared with the landscape analysis. On this basis, the authors translated the results into 15 concise, assessable theses, which are documented in the appendix and form the basis of the survey.

Step 3 – Online survey of experts

In January 2026, 46 experts from Fraunhofer CCPE (including the Advisory Board) and the "KIOptiPack" and "K^{3}I-Cycling" projects evaluated the 15 theses on a scale from 1 (low agreement) to 5 (high agreement) in an anonymous online survey ("Survey on the use of AI in the plastics value chain by 2030"). In addition, free-text comments on reasons, risks and research needs were collected. The survey provides a qualitative, expert-based description of the situation; it is not representative for the entire industry or research landscape.

Step 4 – Evaluation and derivation of recommendations for action

The quantitative assessments were evaluated descriptively (mean values, ranges, proportions with high/low agreement). The free-text responses were grouped into categories (including database, regulation, economic efficiency, acceptance, *governance*) using qualitative content analysis. This revealed patterns of broad consensus, controversially discussed topics and heterogeneous assessments. The results were compared with and validated against the findings of the landscape analysis. On this basis, prioritized recommendations for action were derived for industry, research, and politics, which are presented in the following chapters.

Quality assurance and limitations of the survey

All content from the landscape analysis is based on publicly available sources. The AI-generated theses were generated with the help of a documented guideline and then cross-checked with the landscape analysis, converted into clear theses and critically evaluated by the experts according to defined criteria. Risks associated with generative AI (e. g., simplifications or hallucinations) were mitigated through plausibility checks, cross-references to standards/regulations and validation by the expert survey.

The results primarily reflect research-related and project-related perspectives and do not claim statistical representativeness. However, they provide a transparent, structured basis for the positioning of Fraunhofer CCPE with complementary perspectives from some partners from the AI hubs for plastic packaging. Detailed methodological documentation, including survey evaluation and excerpts from the AI dialogues, can be found in the appendix.

3 Landscape analysis

The plastics industry is increasingly taking a positive stance on AI, with a focus on efficiency, quality and recyclability along the entire plastics value chain. Associations, companies and initiatives are addressing AI as a key technology for better material quality, lower environmental impact and higher economic efficiency, while at the same time gaps in standards, data infrastructures and the scaling of pilot projects are becoming apparent.

Associations: Plastics Europe identifies AI and digitalization as key levers of transformation. In position papers and speeches, digital product passports, AI-supported sorting and the optimization of design and production are highlighted as core components for high-quality recyclates and resource efficiency [Plastics Europe-2025b]. The joint paper by GKV, VDMA, PlasticsEurope, bvse and BDE emphasizes that "*the potential of AI for applications in new and existing plants* should *be exploited*," particularly in mechanical sorting, in order to enable recyclates of reliable quality that are sorted by type [GKV-2025]. European Bioplastics does not currently have an explicit position on AI.

Companies are visibly driving the use of industrial AI through several flagship applications. Covestro pursues a strategic AI transformation (Chief AI Officer, rapid user scaling, autonomous production lines, shorter planning cycles) and sees AI as a colleague and competitive factor [AI First-2025]. Evonik demonstrates practical applications in mechanical recycling with robot- and sensor-based AI sorting [Rademacher-2021]. Clariant establishes "Clarita," a company-wide AI tool for laboratories, production and customer interaction, and is relying on a bottom-up approach with strong data security [Clariant-2025]. Pöppelmann builds expertise and acceptance through a digital lab and the internal assistant "MIA," supported by regional networks [Pöppelmann-2025]. Plant and technology providers such as KraussMaffei and Reifenhäuser focus on digitalization, data analysis and automatic process optimization; Reifenhäuser bundles this under "NEXT" with seamless integration of industrial AI [KraussMaffei-2025, Reifenhäuser-2025]. TOMRA addresses transparency and quality assurance in the sorting process with *deep learning* and *cloud analytics* (TOMRA Insight, stake in PolyPerception) and predicts AI as a driver for higher-value recyclate markets [Tomra-2025].

In October 2025, the K trade fair, the world's leading trade fair for plastics and rubber, took place in Düsseldorf. There, the positions and market dynamics on the topic of AI and plastics were confirmed. In addition to cross-cutting panels (Transformation, Investments, "Plastics – the fast Facts"), there was a whole day at the trade fair with a packed AI program: "AI & Digitalization for a Plastics Circular Economy," "AI-Powered Material Intelligence" and sessions on AI in recycling (e.g., sensor-based sorting) marked the main topics. Guided tours such as "Next Level Production: AI and Digitalization" brought industrial AI to life in various companies and underscored how AI is converging in design, sorting, production and sustainability assessment.

Politics and the public sector: At the EU level, regulations such as the "Packaging and Packaging Waste Regulation" (PPWR), the EU "Ecodesign for Sustainable Products Regulation" (ESPR), further initiatives on digital product passports and the "AI Act" are driving the framework for data-driven, trustworthy AI applications in the plastics industry. They provide impetus for design-for-recycling, recycled content quotas, transparency and *data governance* - but without yet providing specific guidelines for the use of AI in the plastics value chain. In terms of funding policy, the EU and the

German Federal Government (including Horizon Europe and national programs) support pilot projects and cooperation along the value chain. At the same time, concrete standardization, especially for data models and interface links, *interoperable data spaces* and interim financing from prototype to industrialization often remain insufficiently addressed. This lack of prioritization has a dampening effect on investment – including R&D activities and direct research contracts from industry: Although companies are conducting initial demonstrations, they are rarely moving on to broad-based testing – presumably because investment barriers are high and there is a lack of robust, scientifically sound evidence of the added value of AI (quality, costs, sustainability) and of the avoidance of negative effects (pure job cuts, increased dependence on third-party providers). Conclusion: The political framework favors AI as an enabler of the circular economy, but an explicit, sectoral AI strategy for plastics and application-oriented test beds and scaling-oriented funding lines are still lacking.

Across the board the picture is becoming clearer: AI improves sorting quality and throughput, reduces waste, stabilizes processes, shortens development cycles and can significantly reduce the carbon footprint through better material selection, higher recycled content rates and automated life cycle assessment (LCA). At the same time, three bottlenecks are prominent: a lack of standardization (data models, testing and interface standards, digital product passports), inadequate data and IT infrastructures (secure, *interoperable data spaces*) and financing gaps in the transition from pilot projects to continuous industrial operation.

CCPE's agenda until 2030 takes shape: In the short term, the establishment of standardized data models and product passports, reference demonstrators in sorting and production and scalable training and change programs; in the medium term, the coupling of material and production data spaces with AI-supported research (material intelligence) and the first autonomous lines in routine operation; in the long term, the broad industrialization of trustworthy AI with measurable quality, cost and climate targets. The role of research alliances such as Fraunhofer CCPE is to close the gap between technology maturity and market scaling as a neutral data trustee, operator of test beds and bridge builder to standardization and policy bodies – together with industry partners, AI hubs and associations.

4 Expert survey

A total of 46 people took part in the expert survey entitled "Survey on the use of AI in the plastics value chain by 2030" in January 2026. They were affiliated with Fraunhofer CCPE, its advisory board with representatives from industry, research and public administration, as well as projects from the AI hubs for plastic packaging "KIOptiPack" and "K^{3}I-Cycling". Four participants belong to both Fraunhofer CCPE and one of the two BMFTR-funded AI hubs for plastic packaging (see0).

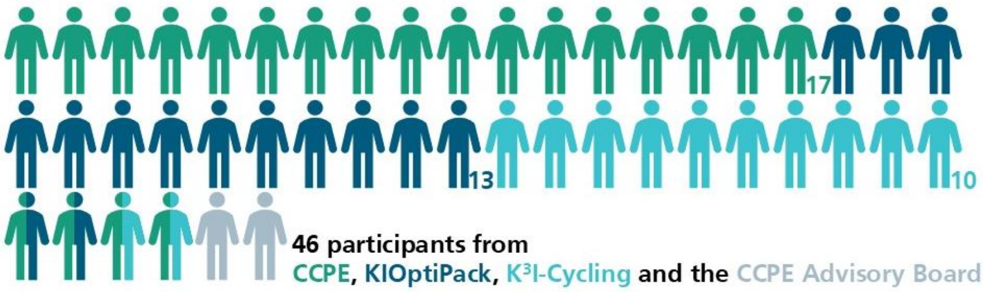

Fig. 02: Affiliation of participants with research initiatives

80 % of participants (37 people) identified themselves as belonging to the research sector, 17 % (8 people) to the industry sector and 3 % (1 person) to the public administration/NGO/non-profit sector. In terms of topics, participants focused on material development and production (24 %, 17 participants), logistics and sustainability (15 %; 7 participants), collection, sorting and recycling (24 %, 11 participants), and other areas such as management or software and AI development (24 %, 11 participants) (see Fig. 03). The "other" category includes various areas such as management, marketing and AI/software development.

Fig. 03: Affiliation of participants along the value chain

Regarding individual AI experience, participants assigned themselves to the selectable experience levels; the exact distribution can be seen in Fig. 04.

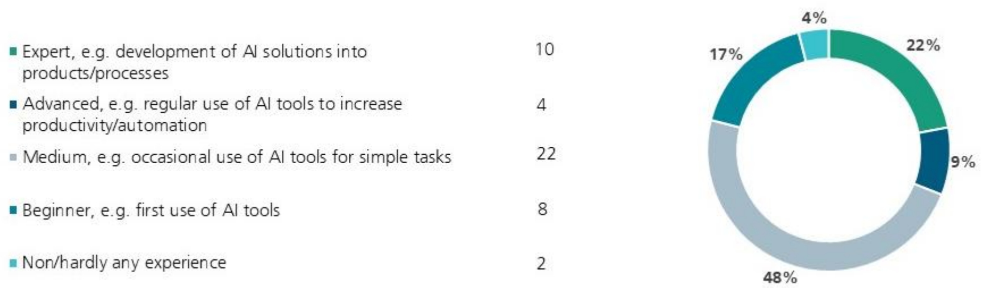

Fig. 04: Level of experience of participants

Due to the selection and approach of participants via relevant distribution lists and the sample size, the results presented below are a qualitative, expert-based description of the situation. They are not representative of research and industry as a whole but support the positioning of Fraunhofer CCPE and the AI hubs with regard to the use of plastics along the value chain until 2030.

The 46 participants described the greatest opportunity offered by using AI in one word (see Fig. 05). The opportunity terms were mainly grouped around the keywords: automation, efficiency and resource savings.

Fig. 05: Word cloud of the opportunity terms mentioned for using AI in the plastics value chain

The risk terms mentioned were grouped around the keywords: dependencies, misinterpretation, lack of transparency and loss of control (see Fig. 06).

Fig. 06: Word cloud of the risk terms mentioned in connection with using AI in the plastics value chain

AI is primarily seen as a lever for operational efficiency and resource gains, while the central concerns are less technical in nature and relate more to control, transparency, *governance* and vendor dependencies. Accordingly, the research agenda and policy framework must address efficiency potential and control and trust issues at the same time.

The quantitative evaluation of the 15 AI-generated theses shows a consistently high level of agreement. All average values are between 3.6 and 4.4 on the five-point scale. The strongest support was given to operational statements on clearly defined automation tasks, the role of a reliable database and the economic relevance of AI-supported efficiency gains. Somewhat lower, but still predominantly positive, were more normative statements on regulation, the 2030 target vision and new business models. Nevertheless, the range from 1 to 5 can be found at least once among different experts for almost all theses. At the same time, the ratings make it clear that individual aspects such as regulation and data sharing are viewed controversially. The following qualitative evaluation picks up on these patterns; the complete statements and detailed evaluation results are documented in the appendix. Direct quotes from participants in the free text fields are highlighted in the text.

4.1 Status quo and need for action

The survey paints a consistent picture of the status quo. AI is currently capable of performing clearly defined tasks. Functioning applications are available, particularly in image processing and optical quality inspection, automated sorting of defined material flows and process control of individual plants (e.g., injection molding with recyclates).

The current move towards integrated, cycle-oriented solutions fails mainly due to the following conditions:

- heterogeneous, incomplete and often non-machine-readable data,
- a lack of standards and *ontologies* (polymers, additives, formulations, process parameters, recyclate classes),
- fluctuating recyclate qualities and complex material composites,
- lack of *interoperability* between IT systems and interfaces,
- insufficient incentives and business models for data sharing.

The majority of respondents are clearly in favor of AI, with a focus on efficiency, quality and recyclability. At the same time, respondents point out that in the funding landscape and business practice, many AI applications remain in the pilot stage and are rarely scaled-up to continuous industrial operation. The main reasons are uncertain business cases, a lack of standards, and unresolved governance issues.

The survey reveals various areas where action is needed by 2030. The development of hybrid, explainable models for material properties and process windows, especially for recyclates and biopolymers, should be advanced in the following areas.

- Expansion of *inline/nearline sensor technology* and AI-based soft sensors for continuous quality assessment during sorting and recycling.
- Development of *domain-specific data standards* and *ontologies* for material, process and quality data.
- Development of uncertainty-aware AI (uncertainty quantification, deviation detection) as a basis for auditability.
- Establishment of living labs or testbeds for continuous testing of AI in real value chains.
- Methods for assessing the environmental impact of AI (LCA of AI-supported processes).

4.2 Data availability, data spaces and data protection

"Without a common, reliable database, all further AI and digitalization approaches in the plastics value chain [will] remain piecemeal."

Data is the central resource for the use of AI. Without a high-quality, *interoperable*, and trustworthily shared *database*, AI remains limited to isolated solutions. Among the respondents, there is a particularly clear focus on the following points as key levers:

Interoperable database: A shared or *interoperable*, reliable *database* is considered the most important lever for the meaningful use of AI. This refers in particular to:

- material data (recipes, additives, aging),
- process data (parameters, states, malfunctions),
- quality indicators (quality grades for recyclates),

- life cycle data (use, end-of-life).

Instead of a central database, *federated data spaces* with clearly defined interfaces and a high degree of *interoperability* are considered more realistic.

"Data availability is not the problem but the documentation. Often, the data is stored somewhere unstructured or poorly documented. Historically, our data repositories are readable by humans and not by machines. New structures are needed to make data available securely for AI applications and across multiple stakeholders in the long term."

Data availability vs. willingness to share data: There are differing interpretations of the term "data availability":

- A part of the experts emphasizes the relevance of data gaps (missing measurements, poor documentation, poorly structured data).
- Another group sees the main problem in a lack of willingness to share data (data hoarding). They mention the fear of losing competitive advantages, unclear business models and a lack of incentives.

"It seems that companies have no sufficient (economic) interest in creating an interoperable database."

This makes it clear that the problem is not only technical, but above all governance- and incentive-driven.

Data protection, IP protection and platform dependency are particularly frequently discussed among respondents:

- Traditional data protection (personal data) is predominantly considered manageable in the production context.
- More critical issues are the protection of sensitive company data (recipes, process strategies), the risk of data leaks and dependence on large platform providers.
- Trust models, neutral *data spaces* and secure platforms are seen as options; however, *governance*, business models and international enforcement remain open questions.

At the same time, there is a high level of agreement that open interfaces, standards and reference data are essential to limit vendor lock-in and enable *interoperability*. It is emphasized that open tools already exist, but market logic often favors proprietary solutions. Isolated solutions are sometimes seen as unavoidable as long as they are fundamentally compatible.

4.3 Profitability and new business models

The economic perspective is crucial for respondents. **AI is considered economically viable** if it:

- reduces waste, energy and material consumption,
- increases quality consistency,
- runs robustly across locations and can be proven to be economically viable.

The biggest **obstacles** currently are:

- high integration, maintenance and verification costs,
- difficult-to-assess cost-benefit ratios,
- fluctuating performance in real-world operation,
- uncertainty about liability and insurability in the event of wrong decisions.

Economic efficiency is primarily anchored in international competition and market pressure.

"I believe that the most important driver for expansion is pressure from the (international) market. Without disruptive impulses, maintaining the status quo offers sufficient advantages."

However, many respondents also see **new business areas**, particularly in the following fields:

- quality and process services ("Quality as a service"),
- testing and verification services (e.g., life cycle assessment, recyclate verification, auditing),
- data-driven services along the value chain.

It is emphasized that in some cases, the perceived benefit is more important than perfect AI solutions, which promotes acceptance and new business models:

"Economic efficiency can only be achieved if AI delivers real practical benefits. The quality of AI can be subordinate if the user experience is unique."

Prerequisites are demonstrable willingness to pay, viable liability models and clear business cases, especially for original equipment manufacturers (OEMs). Otherwise, AI solutions will remain in the pilot phase. Several voices point out that this requires demonstrable willingness to pay, clear liability regulations and attractive business models for companies.

"AI enables new scalable, standardized quality and process analyses across plants and companies, thus creating new services (PaaS). Unclear [are] willingness to pay and pricing models [as well as] liability and insurance issues in the event of wrong decisions."

4.4 Regulation, policy and standards

The role of regulation is viewed ambivalently by the experts surveyed:

Arguments in favor of regulation:

"No one can seriously assess the long-term risk posed by AI at the current pace of development. Policy makers should regulate strictly across the board. An unknown risk should always be classified as high when it comes to such a profound technology."

Risk-oriented regulation (e.g., EU AI Act) is generally supported. It can build trust, establish uniform verification standards and strengthen Europe's role in the trustworthy use of AI.

Critical perspective on regulation:

"I tend to think that the legal framework could slow down the development of AI, rather than its use."

Some experts see the danger of overregulation, bureaucratization and barriers to innovation. In particular, they emphasize the risk of competitive disadvantages compared to less regulated markets (including the US and China). Many experts share the perceived discrepancy between the speed of political processes and the dynamics of AI development.

According to the respondents, the practical implementation is essential. Safety- and quality-critical applications must be strict, but manageable in practice. The bureaucratic burden, especially for smaller companies and research, must remain manageable. If regulation is linked to funding policy and market incentives, standards and standardization for data models, interfaces and testing procedures are seen as complementary measures to provide investment security, avoid isolated solutions and establish *interoperability*.

4.5 Acceptance, competencies and the role of humans

In the area of acceptance, competencies, and the role of humans, there is broad consensus on key points:

Conditions for acceptance: AI is accepted when

- the benefits are clearly visible (e.g., better quality, less waste),
- the results are explainable and plausible (explainable AI),
- responsibility and decision-making rights for liability-related issues remain clearly with humans.

"The effect described is partly based on false expectations [...]. Humans also hallucinate, for example when answering the question about the cause of a complex machine malfunction. However, we are used to this, whereas tolerance is very low when it comes to AI. It's a matter of classic change management, as with any new technology, which is not specific to AI at all."

And yet, the following still applies: Acceptance declines with black box systems, recognizable hallucinations/errors and unclear distribution of liability.

"Benefits, explainability and clear human responsibility create trust and acceptance."

Bridging skills: Respondents see combined skills from

- material and process knowledge,
- data comprehension and AI know-how,
- operation and monitoring of AI systems

as key factors. Risks include loss of knowledge (unlearning process knowledge), dependence on a few experts or external providers, and AI-specific insights that are difficult to transfer.

"The question is whether, in the long term, we will forget our own know-how/skills through the use of AI because we rely on the new intelligence."

Division of tasks between humans and AI: There is broad consensus that repetitive, clearly defined tasks will increasingly be automated, while decisions involving safety or liability risks will remain with humans for the time being. However, some believe that AI could make safer decisions than humans in specific areas in the medium term and question whether human final decisions always make sense. Others warn against this:

"Never leave safety or liability risks to automation."

Explicable and hybrid models, systematic knowledge management and continuing education along the value chain are cited as countermeasures.

4.6 Partnerships and priorities for 2030

This chapter summarizes the topics "Roadmap and priorities" and "Cooperation & research needs." The vision of a networked, verifiable data and process chain from design to recycling (including a digital product passport) is confirmed as an important "North Star" until 2030, but 2030 is seen more as an ambitious milestone than a realistic end goal.

"The goal for 2030 is very ambitious. I see high standardization and integration costs, heterogeneous prior experience and implementation and IP conflicts."

Technically, the majority considers many components to be feasible; the bottleneck lies primarily in:

- standardization and integration in heterogeneous corporate landscapes,
- IP conflicts and willingness to share data,
- economic and psychological factors (lack of business case and risk perception),
- coordination at the EU and, where applicable, global level.

Partnerships, living labs or testbeds and shared platforms are considered necessary, but at the same time there is scepticism that without clear *governance* and business models, many parallel, competing initiatives will emerge.

"Proprietary isolated solutions are the curse of our existence."

For this reason, many respondents see the need for alliances and industry-related research activities as a link between research and industry.

Several experts point out the different roles played by small and large companies. For small and medium-sized enterprises (SMEs) in particular, this often means disproportionately high integration, data and compliance costs, even though they have fewer resources. Large corporations and plant manufacturers could drive standards and *data spaces* from above in order to secure clear competitive advantages for themselves. Some experts emphasized the need for specific support for SMEs, particularly in the area of waste management and recycling.

"Today's recyclate suppliers are often SMEs, which cannot afford the necessary investments and are left to deal with the issue on their own."

The need for collaborative research in the field of sustainability assessment was also highlighted.

"A common and consistent database is an opportunity for sustainability assessment, which is often based on assumptions and boundary conditions for upstream and downstream processes."

AI itself has considerable energy and resource requirements (e.g., for training and data centers). The net effect on society and the environment is not automatically positive. Several experts point to the need for research to systematically assess the ecological footprint of AI-based solutions in the context of the circular economy of plastics.

However, among the priorities for 2030, some respondents also make it clear that although AI is a key lever for utilizing and closing data, material and process gaps, it does not replace traditional levers such as good design, robust infrastructure and clear regulatory guidelines.

"AI is not a solution for everything. In my view, it is a mathematical method that can solve many complex problems, but it is not the only lever that should be considered. A comprehensive solution for optimizing the plastics cycle requires much more than a mathematical method."

5 Recommendations by 2030

The landscape analysis and the survey of 46 participants from the Fraunhofer CCPE, "KiOptiPack", and "K³I-Cycling" cooperation networks show a high degree of agreement on the fundamental role of AI in the plastic value chain by 2030. At the same time, however, there are also some clear areas of tension when it comes to data, *governance*, regulation and competencies. The quantitative evaluations of the generated theses and the qualitative analysis of the free-text responses allow the following recommendations for action to be derived for research, politics and practice:

5.1 Recommendations for industry and value chain partners

Strategically build up data bases and data quality

- Prioritize the structuring and quality assurance of internal data (material, process, quality) in order to be able to use AI effectively.
- Gradually participate in *interoperable data spaces* with clear rules instead of maintaining isolated data silos.
- Define a minimal but meaningful core set of data that can be shared as a part of the chain without fully disclosing trade secrets.

Use open standards and actively manage vendor dependency

- Focus on open interfaces and industry standards when purchasing new equipment, IT systems and AI solutions in order to limit vendor lock-in.
- Participate in standardization and association activities to contribute your own requirements at an early stage.
- Consciously weigh up proprietary isolated solutions (short-term advantages) and long-term *interoperability* in the ecosystem.

Build bridging skills and knowledge management

- Establish interdisciplinary teams that combine material/process knowledge with data and AI expertise.
- Systematic knowledge management to avoid hiding experiential knowledge solely in *AI models* and prevent loss of expertise.
- Invest in continuing education on data understanding, AI operations, *governance* and regulation along the entire value chain.

Pilot AI in clearly defined, measurable applications

- Start with clearly defined use cases (e.g., optical sorting, quality inspection, process control of individual systems) where:
    - benefits (waste, energy, material savings) are quantifiable,
    - risks are manageable,
    - experience can be gained for more complex, end-to-end applications.

- Accompanying monitoring of performance, costs and risks to enable robust business cases and scaling decisions.

Actively shaping acceptance and responsible use

- Ensure that AI-supported decisions remain explainable and comprehensible to relevant stakeholders.
- Clearly define who bears responsibility and how human decision-making rights are structured in areas relevant to safety and liability.
- Use open communication with employees and the public about the limitations and risks of AI to build trust and reduce unfounded expectations.

5.2 Recommendations for research and research funding

Prioritize *interoperable data spaces*, standards and *ontologies*

- development and testing of *domain-specific data standards* and data models for polymers, additives, process parameters, quality parameters and recyclate classes
- methods and tools for structuring existing company data (processing of pdf/excel-based information, automatic annotation and quality assurance)
- establishment and testing *of federated data spaces* with clear rules on use, liability and remuneration, including reference contracts and governance models

Developing hybrid, explainable and uncertainty-aware AI models along the chain

- combining physical models with AI (*hybrid/neurosymbolic* approaches) for:
  - material property predictions (e.g., MFI, modulus of elasticity, OTR/WVTR, impact strength),
  - process windows and quality stability for recyclates and bio-based plastics,
  - sorting and recycling processes with highly fluctuating input streams.
- developing uncertainty-aware AI (uncertainty quantification, deviation detection, monitoring) as a basis for auditability and regulatory evidence
- strengthening explainable AI solutions in safety- and quality-relevant applications to support acceptance and liability

Establish living labs or testbeds and *end-to-end demonstrators* across the entire value chain.

- establishment and scientific support of living labs or testbeds in which:
  - *data spaces*, sensor technology and AI models are tested in real production, collection, sorting and recycling contexts,
  - technical, economic, and organizational barriers are addressed jointly.

- *best practices* from design to processing and use to recyclate (including digital product passports) as flagship projects that show how data and process chains can be closed in practice

Systematically assessing the environmental and energy effects of AI

- developing assessment methods (e.g., life cycle assessment, LCA) that explicitly take into account the resource and energy consumption of AI systems (training, operation, data centers)
- comparative analyses: net effects of AI use (e.g., less waste vs. more energy consumption) in selected value chains
- derivation of design principles for resource-efficient AI architectures (e.g., lighter models, *edge computing*, efficient training)

Systematically researching socioeconomic, organizational, and psychological aspects

- examination of incentive structures, business models and *governance* mechanisms that trigger data sharing and AI deployment (including the role of large OEMs as drivers)
- analysis of decision-making behavior and risk aversion in companies (game theory, organizational psychology) in order to be able to design AI projects beyond purely technical arguments
- Accompanying research on acceptance, knowledge loss, and bridging skills (material/process + data/AI + operation), including derivation for continuing education and training formats

5.3 Recommendations for policy and regulation

Specify risk-oriented, innovation-friendly regulation

- operationalization of the EU AI Act and other regulations for the plastics sector in the sense of a clear but practicable classification of applications according to risk
- ensure that safety-critical applications (e.g., hazardous substance discharge, quality approval) are strictly regulated but not effectively blocked..
- qvoid excessive bureaucracy, especially for SMEs; provide targeted simplifications and assistance in implementation

Targeted promotion of data infrastructures, standards, and living labs or testbeds

- Support programs that:
  - support cross-company *data spaces*, *data standards* and *ontologies* in the plastics sector,
  - financing of living labs or testbeds where AI solutions are tested in real value chains,
  - relieve SMEs of the burden of investing in sensor technology, data infrastructure and AI skills.

- Provide accompanying support for standardization processes and reference implementations so that open standards become marketable.

Balance IP, data protection and liability frameworks in a practical manner

- create clear, internationally compatible rules for:
  - protecting sensitive company data (recipes, process parameters) while enabling *data spaces*,
  - liability for incorrect decisions made by AI systems in production and recycling,
  - data protection issues at interfaces with citizens (collection, take-back systems).
- promoting trust and data spaces models only where *governance*, business models and enforcement are realistic

Addressing European competitiveness and sovereignty

- political support for European, open AI and data solutions to reduce strategic dependencies on a few global providers.
- consideration of international competition (US, China) in regulation and funding policy to ensure innovation capacity and location attractiveness.
- linking AI strategies with industry, environmental and trade policy to counteract deindustrialization trends.

6 Conclusion

Based on the landscape analysis, AI-supported thesis formation and a survey of 46 experts, the position paper paints a consistent picture of the role of AI in plastics value chain by 2030. The position paper delivers the following key messages:

- AI is already performing well in clearly defined applications in the plastics value chain and is seen as a key lever for increasing efficiency, quality and recyclability by 2030.
- The bottleneck for intelligent, end-to-end circularity lies less in technical innovations than in the lack of *interoperable databases*, standards, governance structures and viable business models.
- Economic efficiency, distribution of costs and benefits, liability issues and a practicable, risk-oriented regulatory framework will determine whether AI solutions are scaled-up from pilot projects to continuous industrial operation.
- AI is an important lever, but not the only one: design for recycling, product simplification, robust collection and recycling infrastructure and clear regulation remain indispensable cornerstones of the circular plastics economy.

Priority areas for action by 2030

1. Establishment and use of *interoperable data spaces* with *domain-specific data standards* and *ontologies* for material, process, quality and lifecycle data as a basis for AI applications and digital product passports.
2. Development, testing and scaling of hybrid, explainable, and uncertainty-aware AI models in living labs and *end-to-end demonstrators,* from design to processing, collection, sorting and recycling – including robust assessments of economic efficiency and environmental impact.
3. Establishment of *governance*, business and training models that enable data sharing, trustworthy use of AI and the development of cross-functional skills between materials/processes, data/AI and operations in industry, research and administration.

Fraunhofer CCPE will drive this agenda forward as a neutral, industry-oriented research partner by co-developing *domain-specific* data and model standards, carrying out demonstrator projects, and, together with the AI hubs for plastic packaging, building bridges between research, industry and politics for a circular plastics economy by 2030.

7 Glossary

Explanation of terms written *in italics*.

Term	Definition/Explanation
Best practice	Tried and tested procedures or solutions that serve as guidance or reference for similar applications.
Cloud analytics	Analysis and evaluation of data in a cloud infrastructure to provide scalable computing power and storage for data-intensive evaluations.
Deep learning	A subfield of machine learning that uses deep artificial neural networks to recognize complex patterns in large amounts of data.
Domain-specific data standards	Subject-specific rules and formats for the structure and meaning of data that enable uniform exchange and sharing of information.
Edge computing	Processing data as close as possible to the data source (e.g., machine, sensor) instead of in central data centers to reduce latency and data volumes.
End-to-end demonstrator	End-to-end demonstration solution or reference project that maps a complete process or value chain and serves as a visible showcase for new technologies.
Federated data spaces	A network of distributed data storage systems in which data remains with its respective owners but can be securely linked and used via common standards, interfaces and rules.
Governance	The entirety of rules, processes and responsibilities that govern how decisions are made, responsibilities are distributed, and controls are implemented in a system (e.g., data spaces or cooperation).
Hybrid/neurosymbolic AI	AI systems combining neural networks with structured, rule-based symbolic AI, aiming at the reduction of noise and a better robustness.
Inline/nearline sensor technology	Measuring systems that collect data for process and quality monitoring directly in the running process (inline) or in the immediate vicinity with a short time delay (nearline).
Interoperable database/data spaces/interoperability	The ability of different systems and organizations to exchange and use data in terms of technology and content in such a way that they work together seamlessly; an interoperable database or interoperable data spaces are standardized and linked accordingly.
Ontology	A means used in data management for structuring and exchanging data for the formally ordered representation of terms and their relationships to each other.

8 List of abbreviations

Abbreviation	Meaning
AI Act	EU regulation on artificial intelligence (EU AI Act). AI stands for artificial intelligence.
BDE	Federal Association of the German Waste Management, Water and Recycling Industry
BMFTR	Federal Ministry of Research, Technology and Space responsible for funding in the context of "AI hubs for plastic packaging"
bvse	Federal Association for Secondary Raw Materials and Waste Management
CCPE	Fraunhofer Cluster of Excellence Circular Plastics Economy
CO_2	Carbon Dioxide
ESPR	Ecodesign for Sustainable Products Regulation (EU Ecodesign Regulation for Sustainable Products)
R&D	Research and Development
GPT	Generative Pre-trained Transformer (class of large language models, e.g., GPT-5)
GKV	German Association of the Plastics Processing Industry
IT	Information Technology
K^3I-Cycling	Research project "K^3I-Cycling" on AI-supported plastics recycling (project title)
AI	Artificial Intelligence
AI hub/AI hubs	(Regional) centers of excellence for artificial intelligence applications
KIOptiPack	Research project "KIOptiPack" on AI in the optimization of plastic packaging (project title)
SME	Small and Medium-sized Enterprises
LCA	Life Cycle Assessment
MFI	Melt Flow Index
Million	million(s)
NGO	Non-Governmental Organization
OEM	Original Equipment Manufacturer
OTR	Oxygen Transmission Rate
PaaS	Platform/Product as a Service
PDF	Portable Document Format
PPWR	Packaging and Packaging Waste Regulation (EU regulation on packaging and packaging waste)
VDMA	Machinery and Equipment Manufacturers Association
WVTR	Water Vapor Transmission Rate (water vapor permeability)

9 List of figures

Appendix

The original AI-generated core theses for evaluation by the experts in the survey are listed below.

No	Core theses
1	AI in plastics value chain works well for clearly defined tasks such as testing, sorting and control. It often fails to deliver end-to-end solutions due to a lack of a common data language, incomplete data, a lack of verifiability and significant fluctuations in production and recycling.
2	The greatest lever is a common, reliable database across the entire value chain. Real-time predictions of material properties, good data quality and clear rules of use/liability for interoperable data exchange are particularly important.
3	The main problem is the poor availability of data (for training AI) or a lack of data from other stakeholders for the continuous operation of AI in production and recycling. Data protection is usually manageable; protecting sensitive company data is particularly challenging.
4	Easy and secure data sharing requires common data formats, clear contracts and (a) common data platform(s). Secure data sharing procedures and neutral trustees increase protection.
5	AI becomes economical when its use saves waste, energy and materials and ensures stable operation across locations. High costs for integration, maintenance and verification, as well as fluctuating performance during operation reduce its benefits.
6	By 2030, new business areas will emerge by using AI in the field of quality and process services as well as testing and verification services. An expansion requires common standards, reference data, clear liability regulations and proven willingness to pay.
7	The legal framework for artificial intelligence slows down the use of AI in the short term but creates trust in the long term. Regulatory frameworks such as the EU AI Act promote the circular economy of plastics because they require uniform data and verification.
8	Policy makers should regulate the use of AI according to risk: strict for high risk, supportive for low risk and good prospects of success. Collaborative test environments, standards, data platforms, and practical guidelines are important.
9	Acceptance of AI use is high when the benefits are visible, the results remain explainable, and humans make the decisions and bear the responsibility. Acceptance declines when results are incomprehensible (black box) and hallucinations become apparent upon closer inspection.
10	By 2030, we will need bridge skills: data understanding, training and operation of AI along the plastics value chain. Material and process knowledge must not be lost when tasks are taken over by AI in the long term.
11	Above all, recurring, clearly regulated tasks will probably be automated/taken over by AI (in the future). Decisions with safety or liability implications should remain with humans.
12	Our "North Star" by 2030 is a networked and verifiable data and process chain from design to recycling, supported by the digital product passport and other data systems. The use of AI can remove long-term hurdles/concerns in the area of recyclate extraction and processing, which will strengthen the circular economy in the long term.
13	Partnerships and competence building with open interfaces and common data rules are crucial. Proprietary isolated solutions increase dependencies and risks when using AI.

14	We need a functioning data platform with open reference data, living labs, and clear benchmarks. Accompanying standardization and research programs accelerate implementation in practice.
15	Dependence on individual providers is currently high. Open standards, data and models as well as clear rules of use reduce the risk.

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