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CREATOR CONSORTIUM

PARTICIPANT NUMBER	ABBREVIATION	ORGANISATION
1	ICT	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung – Institut für Chemische Technologie
2	VLB	Volbas S.A.
3	MOS	Machinefabriek Otto Schouten BV
4	CLR	Coolrec BV
5	REL	Treee SRL
6	GKR	Fundacion Gaiker
7	TCK	Transfercenter fur Kunststofftechnik GmbH
8	RMA	Erema Engineering Recycling Maschinen und Anlagen Ges.m.b.H
9	CTB	Centre Scientifique & Technique De L'industrie Textile Belge
10	MAI	Maier S. Coop.
11	DAW	DAW SE
12	CYC	Cyclefibre S.L.
13	CID	Fundacion Cidaut
14	KLU	Kuhne Logistics University GmbH
15	OVM	Openbare Vlaamse Afvalstoffenmaatschappij
16	RWE	RWEnergia Robert Wudarczyk
17	ITB	ITRB Group LTD

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Openbare Vlaamse Afvalstoffenmaatschappij	OVM	Author of the deliverable 1.8
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MAIER, S. Coop.	MAI	Revision
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung – Institut für Chemische Technologie	ICT	Revision
CREAToR consortium		Support to the study
REMADYL consortium		Revision

LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
ECHA	European Chemicals Agency
EPR	Extended producer responsibility
EU	European Union
HBCD	Hexabromocyclododecane
NADES	Natural deep eutectic solvents
OECD	Organization for Economic Co-operation and Development
PBDE	Polybrominated diphenyl ether
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinyl chloride
POPs regulation	Regulation (EU) No 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants
RC	Recycled content
REACH regulation	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals
sc-CO_2	Supercritical CO_2
SCIP	Substances of concern in articles (products)
SME	Small and medium sized enterprice
SVHC	Substances of very high concern

1 INTRODUCTION

The objective of the CREAToR project, funded by the European Union's Horizon 2020 research and innovation program, is to develop a profitable approach to recycling complex waste streams containing hazardous brominated flame retardants. These substances, such as hexabromocyclododecane (HBCD) in polystyrene (PS) insulation panels, and polybrominated diphenyl ethers (PBDEs) in waste from electrical and electronic equipment and the automotive and aeronautic sectors, are now restricted in new products. The project aims to establish a comprehensive business model that spans the entire value chain of waste recycling and covers:

- The development of a reverse logistics process for efficient collection of waste;
- The development of new sorting and quality control technologies for the detection of brominated flame retardants, that can be implemented in existing sorting processes;
- The development and scale-up of a continuous purification process based on extractive extrusion with supercritical CO_2 and natural deep eutectic solvents (NADES), in which the contaminants are dissolved during the extrusion process;
- Readditivation and demonstration of recycled polymers in new products (3D-printing, thermoplastic foaming and injection moulding techniques);
- The development of a labeling system to easily share information on the material properties and quality of the recyclates.

The project brings together 17 partners from various sectors including industry, research and public authorities to encompass the entire value chain. The presence of prominent industry and recycler partners within the consortium guarantees the practical application and commercial viability of the developments, leading to swift market adoption after the completion of the project.

This deliverable reports the policy brief elaborated in the CREAToR consortium with the support of the REMADYL consortium (GA no 821136) by the main author Roeland Juchtmanns, OVAM.

1. EXECUTIVE SUMMARY

This policy brief is a collaboration between two projects - CREAToR[1] and REMADYL[2] - that aim to develop innovative technologies to recycle plastics with hazardous legacy additives. Both projects cover the entire recycling chain of plastics, from the collection of waste, purifying and recycling the polymer, to the demonstration of the recovered material in demonstrator parts. As such, the two consortia share for a large part the same legal and other obstacles when it comes to developing a circular economy for plastics.

The policy recommendations and the recommendations for further research listed in this brief result from multiple consultations of the partners in both consortia and from a broad stakeholder consultation reaching over 70 companies and organisations in the plastic converting industry. In this document, the two consortia wish to suggest 13 policy recommendations and 11 research topics where there is a need for more knowledge to implement science-based policies, or where there is a need for further technological developments to achieve plastic circular economy goals. The recommendations are divided into three topics that address different aspects of legislation.

- Support market uptake of plastic recyclates
- Ensure a stable legislative environment that stimulates the most effective (combination of) recycling technologies
- Guarantee a safe circular economy for plastics

The document presents a well-considered picture of the problems faced by some partners on a daily basis, and possible solutions to which all the partners can agree. An overview of these policy and research recommendations is provided in the table below.

Topic	Policy recommendation	Research recommendation
Support market uptake of plastic recyclates	PR 1 – Essential considerations and supporting policy measures when introducing mandatory recycled content PR 2 – Promote the properties of recycled plastics PR 3 – Stimulate the economic viability of recycled plastics	RR 1 – How to smartly introduce mandatory recycled content RR 2 – Development of improved recycling and plastic conversion technologies RR 3 – Development of material standards for plastic recyclates

[1] **CREAToR** – EU's Horizon 2020 Research and Innovation Programme, Grant Agreement no. 820477
[2] **REMADYL** - EU's Horizon 2020 Research and Innovation Programme, Grant Agreement no. 821136

Topic	Policy recommendation	Research recommendation
Ensure a stable legislative environment that stimulates the most effective (combination of) recycling technologies	PR 4 – Create a secure investment climate by ensuring clear and stable, ambitious, yet pragmatic legislation on limits for hazardous chemicals PR 5 – Create clear EU-wide definitions for recycling yield and recycled content for new recycling technologies that follow physical material flows PR 6 – Qualify solvent-based purification / dissolution recycling as "Physical Recycling" in the Taxonomy Climate Delegate Act PR 7 – Take the quality of recycling and final application into account when setting recycling rates and recycled content targets	RR 4 – Full life-cycle impact of different recycling technologies, including quality of recycling and combinations of different recycling technologies RR 5 – Research on new characterisation technologies that can monitor legal limits in large-scale continuous recycling processes RR 6 – Research on current and future waste streams and their recycling potential RR 7 – Research on smart logistics for the collection of waste
Guarantee a safe circular economy for plastics	PR 8 – Increase traceability of substances of concern in new products PR 9 – Prevent undesirable substitution from a recycler's perspective PR 10 – Improve control of hazardous substances in imported products to prevent contamination of waste streams PR 11 – Ban the export of plastic waste that potentially contains hazardous substances to non-OECD countries and countries outside the EU PR 12 – Include information on hazardous chemicals in the digital product passport established under the Ecodesign for Sustainable Products Regulation PR 13 – Make REACH regulation more circular in the long term	RR 8 – Scaling-up and development of new purifying technologies RR 9 – Design for recycling from a chemical perspective RR 10 – Responsible use of substances of concern in well-controlled product categories RR 11 – Smart marking/labeling of products for efficient sorting, and how to introduce this onto the EU market

2. INTRODUCTION

Plastics are an essential component of modern life, with an ever-increasing demand for convenience and affordability driving their production. However, this demand has also led to a global plastic waste crisis, with millions of tons of plastic ending up in landfills, oceans, and other ecosystems each year. The linear economic model of "take-make-dispose" is no longer sustainable for plastics, and a transition towards a circular economy is necessary.

A circular economy for plastics aims to keep materials in use for as long as possible, through strategies such as recycling, reusing, and reducing waste. This shift not only reduces environmental pollution but also has economic and social benefits, such as job creation, resource efficiency, and reduced greenhouse gas emissions.

One of the major challenges in transitioning towards a circular economy for plastics is the existence of hazardous legacy additives that were commonly used in the past to improve plastic's performance, durability, and flame resistance. Some of these additives, such as some brominated flame retardants, are now known to be persistent, bio-accumulative, and toxic, or (in the case of low-molecular-weight phthalates plasticisers) reprotoxic and can pose risks to human health and the environment. The presence of these hazardous legacy additives in plastic waste streams makes it challenging to recycle and reuse plastic materials without releasing harmful chemicals into the environment. Additionally, it is difficult to identify and separate these additives from plastics, which makes it challenging to ensure the safety and sustainability of recycled plastic products.

Under the European Union's Horizon 2020 research and innovation program, both CREAToR[1] and REMADYL[2] aim to tackle the problem of legacy additives in a circular economy for plastics by developing innovative techniques to detect hazardous legacy additives in plastic waste and to purify contaminated waste so that it can be recycled. The projects cover the entire recycling and production chain, from collection of waste, and recycling of the polymer, to the demonstration of the purified material in demonstrator parts. As such, they bring together expertise from the recycling industry, plastic processing industry, research and public authorities, into two consortia of 17 partners in CREAToR, 15 partners in REMADYL and 29 distinct organisations in total.

In this document, both partnerships wish to share 13 policy recommendations that can be implemented at EU level or by Member States to achieve or accelerate the transition to a safe circular economy for plastics. The policy recommendations are accompanied by 11 research topics where there is a need for more knowledge to implement science-based policies, or where there is a need for further technological developments to achieve plastic circular economy goals.

The policy brief is structured around three main topics into which the policy and research recommendations can be divided. Each of the following chapters addresses one of these topics and contains three sections with a description of the topic and its relevance to the projects, and a set of policy recommendations and research recommendations.

The three topics are as follows:

Support market uptake of plastic recyclates – The main purpose of these proposals is to increase the use of plastic recyclates by the plastic converting industry. A stable and large demand for high-quality plastic recyclates is essential for the economic viability of the techniques which are developed in our projects.

Ensure a stable legislative environment that stimulates the most effective (combination of) recycling technologies - In this chapter, the emphasis lies on the development of legislation that, on the one hand, is stable so that return on investments for recyclers can be estimated, and that on the other hand stimulates the most effective recycling technologies for specific waste streams. Also, the importance of life cycle analyses is stressed to ensure that the transition to a circular economy for plastics has clear ecological benefits.

Guarantee a safe circular economy for plastics - Both CREAToR and REMADYL are developing solutions for problems that must be avoided in the future, namely the presence of hazardous substances that undermine the recycling of certain waste streams. In this chapter, recommendations are made to ensure a safe circular economy for plastics, focussing both on preventing our waste streams from contamination with hazardous substances and on dealing with the substances that are already present.

The list of recommendations is gathered from expertise within the two consortia, that cover partners from the recycling industry, the plastic conversion industry, research bodies and public authorities. Further input was gathered from an extensive stakeholder consultation among partners in the plastics processing industry. The focus of this study was on the legal and other barriers that plastic convertors experience when using - or making the transformation to use more – recycled plastics. It gathers information from 30 in-depth interviews with partners from the plastic processing industry and a digital survey that reached 51 companies[3]. Although the suggestions that came out of this consultation were presented to the consortia, as extra input for this brief, only the ideas where consensus could be reached are included in this final version.

This publication is a public report by the CREAToR and REMADYL projects funded by the EU's Horizon 2020 Research and Innovation Programme, Grant Agreement no. 820477 and 821136. It aims to provide support to the European policymaking process by sharing expertise gathered in its partnerships. The contents of this publication do not necessarily reflect the position or opinion of the European Commission.

[3] Results of this study can be found in CREAToR's public deliverable "Deliverable Report D1.8 Report of process and end-users' limitations and regulatory gaps" **Publications – CREAToR (creatorproject.eu)**.

3. SUPPORT MARKET UPTAKE OF PLASTIC RECYCLATES

3.1. LINK WITH THE CREATOR AND REMADYL PROJECTS

Both CREAToR and REMADYL aim to produce high-quality plastic recyclates out of thermoplastic waste which recyclability might be limited by the presence of hazardous substances. While CREAToR focuses on the removal of bromine-containing flame retardants from various polymers REMADYL targets the removal of lead and low molecular weight phthalate plasticisers from PVC. Both CREAToR and REMADYL will present the industry a value-creating recycling pathway for this type of plastic waste. However, for the technology to be economically viable, the existence of a stable market for the output material is essential.

The market for high-quality recyclates faces multiple challenges. First of all, there is a stiff competition with virgin material that can be produced at relatively low price, because the producers' responsibility for the end-of-life management of products is rather limited. Also, because of fluctuating prices of virgin alternatives, the demand for recyclates is very unstable, making it hard for recyclers to invest in the production of high-quality recyclates. Finally, a lack of trust in the quality of recyclates has resulted in a significant amount of plastic being recycled into inferior goods, hampering the maximum potential of these materials. We believe strong policy intervention and further research are needed to overcome these problems and to push the market for high-quality recyclates, keeping in mind that increasing the recycling rate of plastics should not be a goal on its own, but must create social, ecological, and economical added value.

3.2. POLICY RECOMMENDATIONS

Policy recommendation 1 – Essential considerations and supporting policy measures when introducing mandatory recycled content

The introduction of mandatory recycled content, as already proposed in several product-specific regulations and initiatives[4], in specific product categories, will increase market demand for recyclates. It can thereby offer economic benefits for recyclers and can be a strong incentive to invest in necessary technologies and collection systems to produce more recyclates that meet the needs of high-quality applications.

In setting product-specific recycled content targets (RC-targets), it is important to consider that not all plastics waste streams and polymer types are equally easy to recycle, or available on the recycling market in the quality required and in sufficient qualities, or have the same overall positive ecological impact when virgin material is replaced with recyclates. For each material type and each product category in which the introduction of obligatory recycled content is considered, policymakers shall take into account:

- What is the ecological gain of RC-targets for specific product categories and material types? (see research recommendation 4)
- What is the potential growth of the recycling market? Which polymer types currently are being disposed of but have a large potential to be recycled into high-quality material? (See research recommendation 6)
- What RC-targets are feasible with the best available recycling and production technologies?
- Will there be enough recyclates in sufficient quantity and quality on the market to meet the needs of specific applications to reach the RC targets?

[4] A EUROPEAN STRATEGY FOR PLASTICS IN A CIRCULAR ECONOMY, **Eu-plastics-strategy-brochure.pdf (europarc.org)**; Directive 94/62/EC on Packaging and Packaging Waste (PPWD); **EU mulls mandatory recycling targets for construction, automotive, and packaging | ICIS**

We wish to emphasise the importance of sufficient availability of recyclates that meet the needs of the application to reach RC-targets. According to recent research[5], RC-targets that don't sufficiently consider stock of goods and materials create the risk of stimulating the production of short-lived products that increase the offer of secondary raw material on the market, but don't contribute to a sustainable economy for plastics. Moreover, when not enough secondary raw materials are present, prices will skyrocket and fraud by producers buying extra virgin material and selling it as production drop-out at a higher price will become a real risk.

The introduction of mandatory recycled content will also create additional costs for plastic converters, and therefore extra competition with products made abroad will become a reality. To create a level playing field with producers outside of the EU, this measure must also be enforced on imported products. To deal with the costs, suggested measures are to provide financial stimuli for the use of plastic recyclates (e.g., by reducing the price of recyclates or reducing taxes), to compensate necessary investments associated with the transformation of the existing production processes to allow the use of recyclates in new products and to financially stimulate recyclers to produce more high-quality recyclates.

Policy recommendation 2 – Promote properties of recycled plastics

The demand for plastics recyclates will strongly benefit from a wide acceptance of such materials, and consequently products with recycled content will benefit from the end-users' preference. It is however essential not only to promote recycled plastics' content but at the same time to stay focused on the performance of such materials in the new applications.

The requirements of converters are often specified according to the performance profile of virgin polymers. As the performance profile of recyclates generally differs from that of virgin materials, the use of recyclates by converters might not be the preferred option, even though their properties would fulfil the actual requirements of the application.

A demonstration of the use of recyclates in marketed products with defined performance is therefore needed. The use of recyclates in some products, e.g., packaging of detergents and packaging body hygiene products, is being promoted[2], but this can be strongly boosted, e.g. in the promotion of demonstrators in publicly funded projects. These demonstrators are commonly not confidential, and their performance and aesthetics can be analysed for the public. Furthermore, standards may ask for more than is actually needed to provide the required performance over time, and exclude the use of recyclate. Attention should therefore be paid in product standards to allowing the use of recyclate.

Policy recommendation 3 – Stimulate the economic viability of recycled plastics

We note that in certain cases the price of primary raw materials (and their derivatives or semi-finished products) is volatile and sometimes the primary raw materials can be cheaper than recyclates (especially high-quality recyclates). To stimulate the uptake of recycled plastics, it is appropriate to introduce measures that incentivise the use of recycled plastics.

Reduction of recyclate prices could be achieved by providing financial stimuli directly to plastic convertors for using plastic recyclates, e.g., VAT reduction for recycled plastics. Also, the reduction of the costs for recyclers to produce more higher-quality recyclates could be achieved by providing subsidies for investments in better sorting lines and purifying technologies or reducing taxes on labour for the recycling sector, are possible pathways.

Further, alternative routes for stimulating the use of plastic recyclates are attracting more attention, e.g. the introduction of a levy on virgin non-sustainable feedstock or an increased CO2-emission tax. This would lead to higher costs for plastic convertors and, when simply applied to plastic products manufactured inside the EU, to altering the market significantly, and to a competitive advantage for non-plastic industries. To ensure

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[5] Piero Saltion et. al. :**Remanufacturing and recycling as process systems, Volume101, Issue1, January 2023, 283-294, https://doi.org/10.1002/cjce.24625**

the competitiveness of our European plastic convertor sector, it is crucial that the potential introduction of such measures is carefully analysed and the negative impacts on the plastics industry adequately mitigated. Potential trade-offs must be studied as well, so that the achievement of other green goals, such as for example those stimulating better insulation of houses, are not hampered by increased raw material prices.

3.3. RECOMMENDATIONS FOR FURTHER RESEARCH

Research recommendation 1 – How to smartly introduce mandatory recycled content

Introducing mandatory recycled content for certain materials or products may have unintended consequences like diverting high-quality recyclates towards low-quality products or a lack of innovation in other sectors because of the low availability of recycled material on the market. Also, the secure availability of recyclates that meet the quality of products with RC-targets, is of crucial importance.

Research is needed on how to smartly introduce recycled content in sectors or product families for which competition for available recyclates is already fierce and the potential for increased availability with better collection and new recycling technologies or investments is low[5]. Also, the economic and ecological impact of closed-loop recycling to maintain the quality of the material for as long as possible versus open-loop recycling which can increase collection and recycling efficiency must be further examined.

Research recommendation 2 – Development of improved recycling and plastic conversion technologies

Many plastic conversion technologies used today produce high-quality products in ultra-fast, large-scale, and continuous processes. Unintended traces of contaminants or input material with inhomogeneous technical parameters can easily cause major production time and material loss (think of a continuous thin film extrusion process that can be completely shut down by a single grain of sand or small variations in the melt flow of the input material).

We acknowledge the effort made by the EC by funding numerous projects to develop new recycling and plastic conversion technologies[6]. Yet, further scale-up and exploration of new ideas remain necessary to achieve a maximal circular economy for plastics. This includes in particular the development of new plastic conversion technologies that can handle trace contaminants and variations in the properties of input materials, as well as improved recycling technologies to produce high-quality recyclates.

Furthermore, small and medium-sized enterprises (SMEs), who often lack the manpower and budget, can benefit from targeted financial incentives to set up small-scale experiments to add recycled content to their products. The inclusion of SMEs as a parameter for granting EU-research projects could be a way to stimulate further uptake of recycled plastics in SMEs.

Research recommendation 3 – Development of material standards for plastic recyclates

A great number of plastic material properties influence their processing behavior and the quality of the end product. Nearly all of these properties are influenced during the recycling process, which makes it difficult to predict how the recyclates will behave when converted.

The search for and acquisition of appropriate recycled material are complicated because of the lack of clear and uniform standards for plastic recyclates to provide the necessary information on the material properties. Research on the technical parameters that should be included in these standards, on their determination and their implementation in analysis procedures EU-wide, would make it easier for end users to source appropriate materials, and would give clear targets for recyclers to produce high-quality recyclates

[6] E.g. CREAToR and REMADYL, see also European Commission's project database CORDIS, **CORDIS | European Commission (europa.eu)**

according to the existing market demand. Standards that provide information on the converting technologies and end-applications for which the material is suited can further stimulate recyclate uptake.

4. ENSURE A STABLE LEGISLATIVE ENVIRONMENT THAT STIMULATES THE MOST EFFECTIVE (COMBINATION OF) RECYCLING TECHNOLOGIES.

4.1. LINK WITH THE CREATOR AND REMADYL PROJECTS

The extractive extrusion processes currently being developed in CREAToR and REMADYL are new technologies that make it possible to recycle waste streams containing hazardous legacy substances that, up to now, were impossible to recycle. They differ from classical mechanical recycling in that they use solvents to selectively remove certain chemicals from the polymer matrix. They also differ from chemical recycling processes because they leave the polymer chains intact so that they can be directly reused in new products with minimal energy consumption and material losses.

Many different technologies are being developed to recycle plastic waste, all of which have their own (dis)advantages when it comes to environmental impact, recycling yield, quality of output material, and types of waste streams that can be handled. We believe that there is no "one-size-fits-all" solution for achieving a maximal circular economy for plastics, and that a combination of different technologies, applied to different waste streams, will be the most effective.

With the development of new technologies, changes to existing legislation are imminent. Further changes are imposed because of advancing scientific understanding of the harmfulness of some substances to humans and the environment, leading to further reductions in limits for unintentional trace contaminants. These necessary regulatory changes, however, do not contribute to creating a safe investment climate for new recycling technologies, which benefit from a clear, long-term, and stable regulatory framework.

In this section, we want to address some issues related to changing product and waste legislation, and make policy and research recommendations so that the changes made today are sustainable, take a long-term view, and support an efficient recycling industry.

4.2. POLICY RECOMMENDATIONS

Policy recommendation 4 – Create a secure investment climate by ensuring clear and stable, ambitious, yet pragmatic legislation on limits for hazardous chemicals.

Waste and product legislation have a strong impact on the technologies that can be used in the recycling processes of plastic waste and the production processes of plastic articles. Regulation that limits trace contaminants in new products, e.g., the POP[7] and REACH[8] regulation, put strict requirements on detection, sorting, and purification technologies used in recycling. To create a safe and attractive investment climate for new recycling and production technologies, it is crucial that legislation on the restriction of chemicals:

- Provides stability on clear long-term targets, so return on investments in the recycling industry can be correctly estimated.
- Is strict and ambitious from the outset, so that it is futureproofed and can withstand progressing scientific knowledge regarding chemicals of concern.
- Is realistic in implementation and provides limits that are measurable in existing or near-future continuous recycling processes.

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[7] **Regulation (EU) No 2019/1021** of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants

[8] **Regulation (EC) No 1907/2006** of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals

- Considers exemptions for substances where safe usage AND recycling processes are already established.

We acknowledge that these criteria are somewhat conflicting, and we therefore emphasise the importance of scientifically based policy, comparing environmental and societal risks of controlled usage of certain chemicals, with the benefits of a circular economy for plastics.

Policy recommendation 5 – Create clear EU-wide definitions for recycling yield and recycled content for new recycling technologies that follow physical material flows

In classical mechanical recycling and most physical recycling processes, the recycling yield is easily calculated as the mass of the output material divided by that of the input material. Also, generally, a negligible amount of new material is added during recycling, and the recycled content of the output streams usually approaches 100 % (i.e. all polymers in the output streams originate from plastic waste).

In several advanced recycling technologies like chemical recycling, virgin material is added at various points in the process to increase the quality of the final product or to maintain a chemical process. Depending on the technology used, in subsequent steps of the process a significant part of the virgin and waste material may still be lost, recovered as energy, or converted into fuels. In such cases, it is less straightforward to determine the total recycling yield of the process or the recycled content of each of the output streams. To ensure a level playing field between different recycling technologies, the definitions for the recycling yield of input streams and the recycled content of the output streams must be clear and coincide as much as possible with the effective material flows within the process, as is the case for mechanical recycling. The definitions for recycling yield as proposed by the JRC's report "Towards a better definition and calculation of recycling"[9] offer a good starting point, and similar definitions and calculation rules must be developed for recycled content. Free allocation of recycled content according to a mass balance approach, where the mass of the recycled waste in the process is freely allocated to one of the output material streams where it generates the most economic value, must be avoided.

Policy recommendation 6 – Qualify solvent-based purification / dissolution recycling as "Physical Recycling" in the Taxonomy Climate Delegate Act

The EU taxonomy for sustainable activities[10] is a classification system for environmentally sustainable economic activities, and is intended to help the EU scale up sustainable investments and achieve its Green Deal targets. The taxonomy gives companies, investors, and policymakers clear definitions for economic activities considered environmentally sustainable. As described in earlier recommendations[11], it is necessary to add solvent-based purification/dissolution recycling and to classify it correctly as "Physical Recycling" in the Taxonomy Climate Delegated Act. Since it does not alter the molecular structure of the polymer, it requires fewer energy-intensive steps compared to chemical recycling. It has a higher separation selectivity than mechanical recycling and allows the reuse of polymers, thus making a significant contribution to each of the six goals mentioned in the Taxonomy Climate Delegated Act.

Policy recommendation 7 – Take the quality of recycling and final application into account when setting recycling rates and recycled content targets

In a truly circular economy, plastics are recycled after each use phase at end of life over and over again. However, in each recycling process, the quality of the output material, and degradation of the polymer with

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[9] Caro, D., Albizzati, P.F., Cristobal Garcia, J., Saputra Lase, I., Garcia-Gutierrez, P., Juchtmans, R., Garbarino, E., Blengini, G., Manfredi, S., De Meester, S. and Tonini, D., Towards a better definition and calculation of recycling, EUR 31409 EN, Publications Office of the European Union, Luxembourg, 2023, ISBN 978-92-76-98958-5, doi:10.2760/636900, JRC131531, **JRC Publications Repository - Towards a better definition and calculation of recycling (europa.eu)**

[10] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088, **EUR-Lex - 32020R0852 - EN - EUR-Lex (europa.eu)**

[11] CREAToR policy brief, **CREAToR policy brief published – CREAToR (creatorproject.eu)**

respect to the incoming material, depends heavily on the technology used and the waste stream that is treated. To preserve the economic value of plastics over multiple recycling cycles, attention must therefore be paid to the quality of the recycling process and the application in which the recyclates are used. Policies that focus only on the recycling rate and recycled content in certain products will stimulate the first recycling cycle of plastics, but their impact on the recyclability and recycling rate of the second life cycle products, and therefore its long-term sustainability, is a lot less known. Policy on recycling yield and recycled content targets should be accompanied by measures to stimulate high-quality recycling.

For this analysis, it is crucial to have clear EU-wide definitions of the quality of recycling, based on scientific evidence - see also research recommendation 4.

4.3. RECOMMENDATIONS FOR FURTHER RESEARCH

Research recommendation 4 – Full life cycle impact of different recycling technologies, including quality of recycling and combinations of different recycling technologies

To include the quality of recycling and ensure the best combination of recycling technologies on different waste streams in EU policymaking (see policy recommendation 4) it is crucial to have clear, scientifically based insights into this matter. Whereas much research is currently being performed regarding new and promising recycling technologies, there is a clear lack of comparative studies between emerging technologies. We are convinced that a circular economy for plastics will benefit from comparative research on:

- What technology is the most effective and economically viable for specific waste streams, taking both recycling yield and quality of recycling into account
- What multi-lifecycle recycling and application scenarios have the best overall life cycle outcome (e.g. mechanical/physical recycling until the polymer is degraded too much, after which energy-intensive upcycling can be considered, vs. continuous upcycling of material)

Moreover, we are convinced that the outcome of such research will contribute to and is necessary for the development of clear definitions of the quality of recycling - see policy recommendation 4.

Research recommendation 5 – Research on new characterisation technologies that can monitor legal limits in large-scale continuous recycling processes

In current recycling processes, many analytical technologies are used to ensure that the output streams fulfill all legal requirements concerning the limits for unintended trace contaminants. However, these limits are subject to advancing scientific understanding and societal evolutions, and are becoming increasingly stringent. They nowadays touch the boundaries of what the most advanced technologies can detect on a lab scale.

To avoid undermining plastics recycling, it is important to develop new detection techniques that can be applied in large-scale, continuous recycling processes. The focus should be both on monitoring the waste more reliably in a continuous manner where possible, and on improved sampling methods where necessary. The first tools to analyse the stream have been developed by Plastics Recyclers Europe with the PRE 1000.[12]

Research recommendation 6 – Research on current and future waste streams and their recycling potential

Although much waste is selectively collected these days, far from everything is recycled. A large recycling potential in both selectively collected and residual waste remains unexploited to date. Moreover, new products are constantly being placed on the market in large volumes, such as insulation panels, solar panels

[12] PRE 1000, **Quality recycling - Plastics Recyclers Europe**

or windmill blades, or any other lightweight structure. Needless to say, these products will have a significant impact on future waste streams.

The effectiveness of current recycling would benefit from research on the recycling potential of waste streams that are not being recycled today. Large differences exist between EU member states on collection schemes and recycling strategies, creating the opportunity for transnational studies on each other's best practices. This diversity should be exploited further by stimulating close collaboration between European research institutions and different local waste agencies to learn from each other's local strategies.

Moreover, research on the recycling potential of future waste streams, based on information on products marketed today, is vital to prepare the recycling industry for the future. Special attention should be paid to the separate collection and sorting of plastics in demolition waste; with the ever-growing share of insulation panels, a significant amount of plastics can be recycled.

Research recommendation 7 – Research on smart logistics for the collection of waste

The effectiveness of any recycling technology is largely determined by the uniformity of the input material. This benefits greatly from the thorough, separate collection of different waste streams. However, with the growing number of separate waste streams, transport and logistics becomes complex, while the economic and ecological impact on the overall recycling chain grows rapidly. With new emerging recycling technologies, research on the most efficient collection schemes and their logistics is needed to secure economic viability and ecological gains.

5. GUARANTEE A SAFE CIRCULAR ECONOMY FOR PLASTICS

5.1. LINK WITH THE CREATOR AND REMADYL PROJECTS

CREAToR and REMADYL are clear examples of how a circular economy for plastics can be made safer by removing hazardous legacy additives. However, every technology has its shortcomings. The necessity of an extra cleaning step in the recycling process increases costs for the recycler, 100 % removal of these substances is impossible and detection of hazardous content in waste streams is not free from error. Since it is impossible to completely remove all harmful substances during recycling, it is necessary to minimise the incorporation of such substances into new products or, when this does happen, to trace and control them as accurately as possible.

In this section, we reach some proposals for dealing with the use of harmful substances in a circular economy for plastics.

5.2. POLICY RECOMMENDATIONS

Policy recommendation 8 – Increase traceability of substances of concern in new products

Techniques to separate waste with hazardous substances from non-hazardous waste have been developed and implemented to guarantee safe recycling compliance with the POP[7] and REACH[8] regulations. Well-known examples are the separation of plastics containing brominated flame retardants using sink/float techniques, or XRF detection techniques to detect specific elements. However, legislation restricting the use of hazardous substances is under constant evolution, and nowadays legal demands on upper limits for unintended trace contaminants, reach the lower detection limit of technologies in place, as previously discussed by CREAToR[13]. Also, with every new substance being restricted, extra demands are placed on existing sorting techniques. The improved trackability of substances of concern in new products offers a way to safely recycle plastics and produce recycles that meet all legal demands.

The SCIPdatabase from the ECHA[14], in which companies can list the products they put on the EU market containing substances of very high concern (SVHC) above 0.1 %, is a very welcome initiative in the right direction. However, as stated in the first ex-post evaluation of the SCIP report[15], the information in the tool should be adapted more to the needs of recyclers for it to be of use in the actual recycling stage, e.g. by providing more aggregated information on product families.

Furthermore, the database is only compulsory for substances that are currently on the SVHC list. To be future-proof, the SCIP database should be extended to substances that have a higher risk of inclusion on the list of SVHC in the future, such as substances that are qualified as hazardous according to the criteria listed in annex I of the CLP regulation. It seems impractical and unrealistic to rely on retroactive measures, such as requesting additional information for products that are still in use, each time a new substance is added to the SVHC list, as an alternative to making the SCIP future proof. Finally, the usefulness of the SCIP database is hampered by the large number of unverified entries, particularly for imported products. This issue should be addressed accordingly.

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[13] CREAToR's contribution to the public consultancy on the Regulation on Persistent Organic Pollutant, **Regulation on Persistent Organic Pollutant – CREAToR (creatorproject.eu)**

[14] **The SCIP database** gathers information on Substances of Concern In articles as such or in complex objects (Products) established under the Waste Framework Directive (WFD)

[15] PWC, European Chemicals Agency First ex-post Evaluation of SCIP, Final report - May 2022 FWC ECHA/2018/452 SC02, **2c677149-e876-f2b1-0ba7-3daca0a419ef (europa.eu)**

The use of other techniques to track substances of concern in new products, such as chemical markers[16] or watermark technologies[17], should also be considered when practical feasibility and effectiveness are proven.

Policy recommendation 9 – Prevent undesirable substitution from a recycler's perspective

Generally, a substance is only restricted when an economically viable alternative exists. However, some of these alternatives turned out to be environmentally ubiquitous themselves and must now be sorted out from the waste streams too. Sorting techniques that work for the original restricted substance may no longer work for their alternative, and thereby hamper the recycling of entire waste streams. The replacement in polystyrene of brominated flame retardants that can be sorted out using sink-float techniques, and their alternatives based on chlorine that cannot, is an example of a substitution that complicates sorting of this waste stream.

When substituting a substance (or family), one must ensure that the alternative meets at least one of the following conditions:

- The alternative is proven to be safe and causes no harm to human health and the environment;
- The alternative can be sorted from waste streams with existing sorting mechanisms to an equal or higher level than the substance it replaces;
- The alternative is constrained to specific product categories where cradle2cradle recycling is already in place.

If the alternative fails to meet any one of these conditions, one must consider allowing the further use of SVHC to avoid introducing an undesirable substitution and the risk of further complications in the recycling process. An important condition for such use is that it is done in a controlled manner, with thorough, selective collection, closed-loop recycling, and the establishment of EPR schemes. This is to avoid contaminating existing recycling streams.

Policy recommendation 10 – Improve control of hazardous substances in imported products to prevent contamination of waste streams

Imported goods show a high risk of containing substances of concern. According to a project coordinated by ECHA's Enforcement Forum[18], in a sample of 1225 imported products checked by national enforcement authorities in 16 EU Member States, 17 % contained a higher amount of SVHC than allowed. Not only can these kinds of products potentially put the buyer's health at risk, but when discarded at end-of-life, these products enter the normal recycling chain, thereby polluting our waste streams and potentially recycled products.

Thorough control of imported goods for SVHCs is necessary to guarantee a safe circular economy for plastics, and efforts to this end must be increased. Also, consumers play an important role and must be made aware that buying products from unknown suppliers poses a potential risk. Apps like Scan4Chem[19], which consumers can use to check SVHCs in products, can make them more aware, and must be made more readily available EU-wide. The introduction of a label that makes it immediately recognisable for the consumer that a product comes from a known and verified supplier, can also be a valid option.

Policy recommendation 11 – Ban the export of plastic waste that potentially contains hazardous substances to non-OECD countries and countries outside the EU

There is a clear lack of traceability and transparency of plastic waste being shipped to non-OECD countries. In principle, the shipping of waste containing hazardous substances is regulated under the Basel Convention, but illegal trade remains persistent. It causes a significant risk for human health and the environment in the

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[16] Polysecure - **Polysecure GmbH - Polysecure**
[17] The Holy Grail Project - **What is the Holy Grail Project? (coda-plastics.co.uk)**
[18] ECHA's Enforcement Forum - **Are imported products safe?**
[19] AskReach – **Scan4chem app for checking substances of very high concern in products launched**

accepting country, but also for the EU economy when this hazardous waste re-enters the EU market through the import of products containing uncontrolled recycled material.

The strict control of the import and export of plastic waste that potentially contains hazardous substances is necessary. However, the detection of these chemicals in all waste streams is impossible. Instead, a general ban on the export of plastic waste from the EU, as recently adopted by the EU's Committee on Environment, Public Health and Food Safety (ENVI)[20], offers a good solution to guarantee the removal of hazardous substances from our waste and to make sure that it will not re-enter our market through new products. Retaining all waste streams within the European Union enables better regulation of waste disposal, facilitates responsible recycling practices where appropriate, and ensures safe disposal or destruction when necessary.

Policy recommendation 12 – Include information on hazardous chemicals in the digital product passport established under the Ecodesign for Sustainable Products Regulation

The Digital Product Passport introduced in the proposal for Ecodesign for Sustainable Products Regulation offers a great way to create more public awareness on the use of hazardous substances in our daily life products, and to provide information across the entire production chain to enable safe and efficient recycling. Access to information being granted on a 'need-to-know' basis creates the possibility to both provide general information on sustainability for the wider public, and detailed information for safe handling without violating companies' confidentiality and

- For consumers: introduce a score on the environmental impact of chemicals in plastic products, in a similar way to the widely recognised EU Energy Label. This score must include the information if the product is produced inside or outside EU, its risk of uncontrolled release of substances of concern into the environment, and how these substances prevent recycling with common recycling technologies.
- For recyclers: disclose information on the use of specific substances in products or product families, when they become restricted by product, REACH, or POP regulation. Since products have a certain lifetime, this information must be disclosed retroactively for all products that are in use, and not only for new products placed on the market.

Policy recommendation 13 – Make REACH regulation more circular in the long term

REACH is a regulation of the European Union, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals. To comply with the regulation, companies must identify and manage the risks linked to the substances they manufacture and market in the EU. They have to demonstrate to ECHA how the substance can be safely used, and they must communicate the risk management measures to the users.

In a circular economy, besides information on how to use a certain substance, it is appropriate that information on the behavior of the substance during recycling is shared as well. A minimal, non-exhaustive list of questions on which information should be provided is:

- Can the substance, or products in which it is used, be recycled or should it be destroyed/ irreversibly transformed after use?
- Under what conditions can the substance, or products in which it is used, be safely recycled?

5.3. RECOMMENDATIONS FOR FURTHER RESEARCH

Research recommendation 8 – Scaling-up and development of new purifying technologies

Advanced purifying technologies offer great potential for decontaminating waste streams with hazardous content while maintaining intrinsic material value within the economy. However, many of these techniques are only in the developing stage and need further technological improvement and significant scale-up to

[20] European parliament - **Waste shipments: stricter rules to protect the environment and human health**

become economically viable. Moreover, entirely new technologies might be possible that are more effective or can treat waste streams that are not yet in the scope of existing technologies.

For the EU to remain a frontrunner in the development of a circular economy with respect for human health and the environment, more research is needed to further improve and scale up existing technologies, and to develop entirely new types of purification that can be more effective.

Research recommendation 9 – Design for recycling from a chemical perspective

To establish a safe circular economy for plastics in the EU and globally, existing hazardous substances or SVHCs must be phased out rapidly. To achieve this, the search for new safe-to-use and safe-to-recycle additives must be enhanced.

To avoid an undesirable substitution, where one harmful substance is replaced by another, the alternative must be examined and approved in terms of its safety, ecological impact when released in the environment and behavior in standard recycling processes, before being placed on the EU market. Moreover, as long as certain hazardous substances are still entering our waste streams, if one cannot distinguish the safe alternative from the hazardous original in existing sorting lines, the products in which it is used cannot be recycled. The alternative should therefore be distinguishable from the original, or products should be labeled so that they can be safely recycled.

Research recommendation 10 – Responsible use of substances of concern in well-controlled product categories

For multiple hazardous substances, sorting techniques exist to separate these from the rest of the waste stream. When they are replaced with alternatives that are not guaranteed to be safe and at the same time cannot be sorted out, the risk is that the entire waste stream will become unrecyclable. Because of this risk, for some well-controlled product families, for which well-controlled recycling is already in place within the same product family - i.e. high collection rates, and sorting out of hazardous substances or containment of substances in well-defined product family - it might be beneficial to make exemptions for the use of certain hazardous substances.

More knowledge is needed on the effect of banning substances of high concern for which recycling methodologies are in place, in favor of substances with unknown risks for which sorting methods don't exist. Research is needed on the conditions to allow the responsible use of hazardous substances in well-controlled product families, and how to responsibly recycle within the product family. This can help to control the growing number of substances placed on the market and the associated risk of undesirable substitution.

Research recommendation 11 – Smart marking/labeling of products for efficient sorting, and how to introduce this onto the EU market

With the endlessly growing list of restricted substances and lowering of their compliant threshold content in materials to the lower detection limit of existing techniques, separating waste with hazardous content is becoming ever more challenging. A solution to this problem is the labeling of products or mixtures so that these can be sorted out in the recycling phase. Many possible ways of labeling are being developed, ranging from digital watermarks (e.g. HolyGrail[17], CurvCode[21]), to chemical markers. Also, there are many options for the inclusion of information, such as the labeling of specific substances of concern, the applicability of the product (food vs. non-food), or a detailed link to the Digital Product Passport.

We are convinced that to be successful, EU-wide implementation of single labeling should be pursued for each waste stream. To choose the best options, more research is needed on new labeling technologies for each product category, and on the information needed to efficiently sort plastic waste according to market demands for high-quality and safe recyclates that are free of hazardous legacy additives.

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[21] **CurvCode | The missing link in sorting**

6. WORD OF THANKS

This list of recommendations is a result of multiple consultations among the partners. As both consortia consist of a wide range of partners, active in various fields in the plastic recycling chain, it was not always that straightforward to align everyone's views on the suggested solutions. However, the final result presents a well-considered picture of the problems that some partners come into contact with on a daily basis, and possible solutions on which all the partners can agree. The writers of this document wish to thank both consortia for their active and constructive contribution to the discussions.