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A Novel Approach for Recycling Polypropylene from Waste Carpet

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Content

- Plastics
- Global plastics production
- Plastics demand by sectors
- Circular economy for plastics
- Life of plastics
- Managing plastics waste
- Polypropylene (PP)
- Solvent-based recycling
- ISOPREP project
- Lab-scale studies
- Conclusions

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Plastics

- a commercially important class of materials
- lightweight, durable, versatile, easily processable, suitable for use in many different applications, have a high strength-to-weight ratio, stiffness and toughness, ductility, corrosion resistance, bio-inertness, high thermal/electrical insulation, non-toxicity and outstanding durability at a relatively low lifetime cost, and unparalleled design versatility
- an enhanced quality of life:
  - bringing comfort, wellbeing, hygiene and safety to our society
  - enabled the production of innovative products and development of innovative solutions
- wide range of applications: building and construction materials, transportation, renewable energy, packaging, medical devices, clothing, household and personal goods, sports, etc.








PlasticsEurope. Plastics – the Facts 2019. 2020. Available from: https://www.plasticseurope.org.
European Commission. A European Strategy for Plastics in a Circular Economy. Available from: https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf
Andrady, A.L. and M.A. Neal, Applications and societal benefits of plastics. Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 2009. 364(1526): p. 1977-1984

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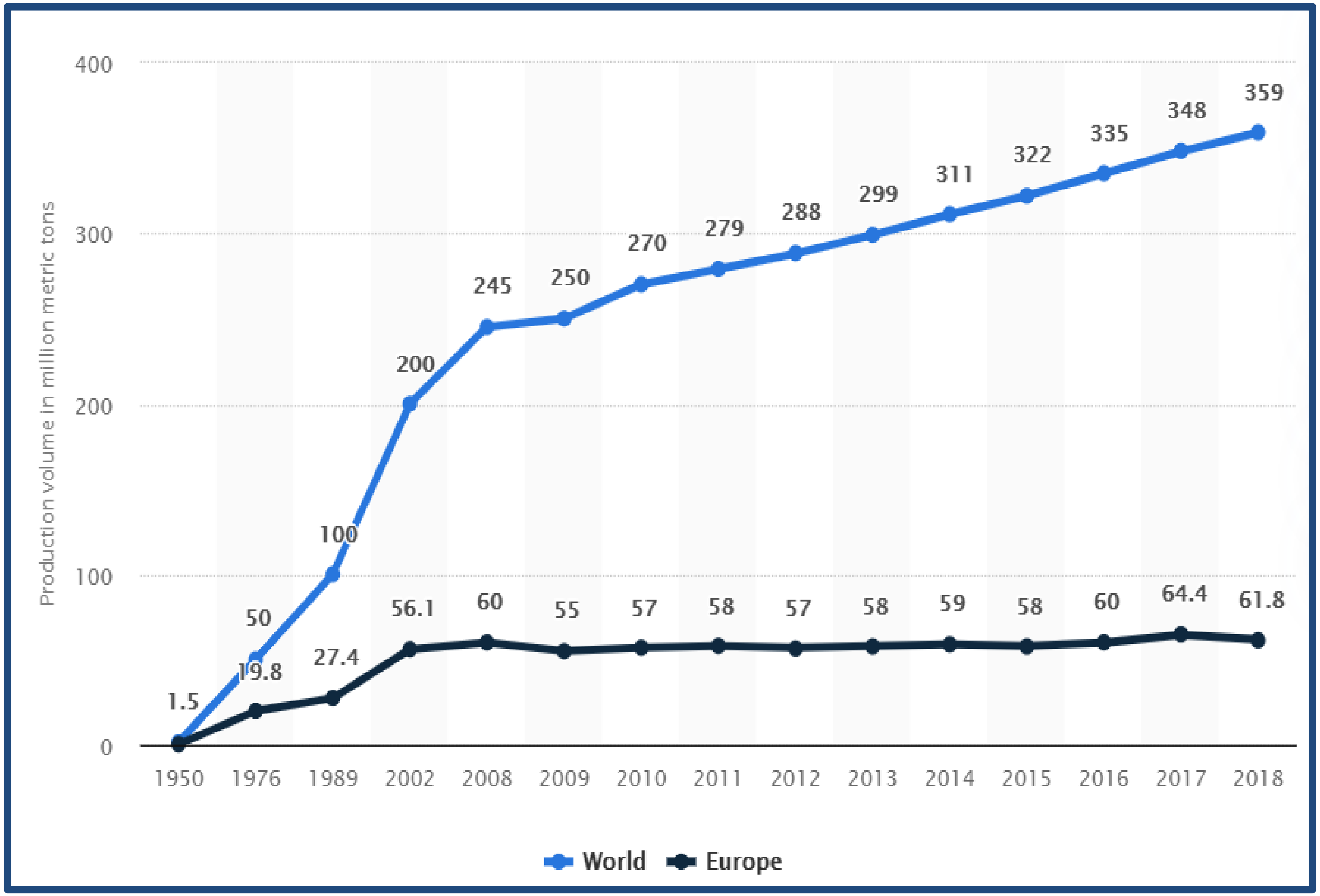
Global plastics production



Global plastics production from 1950 to 2018.

Statista. Global plastic production from 1950 to 2018. 2019 [cited 2020 27 May]; Available from: https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/.

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Plastics demand by sectors

Plastic demand by sectors in Europe in 2018

PlasticsEurope. Plastics – the Facts 2019. 2020 [cited 2020 29 May]; Available from: https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf

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Circular economy for plastics

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- facilitate the circularity of products by
  - increasing resource efficiency and sustainability along the value chain,
  - stimulating economic growth and
  - creating new jobs
- present one of the big challenges to achieving CE as the way they are discarded too often fails to capture the economic benefits of a 'circular' approach and requires a systemic transition, in which they never become a waste or a pollution but circulated back into the system.

PlasticsEurope. *Plastics' Contribution to the Circular Economy*, https://www.plasticseurope.org/en/focus-areas/circular-economy; *Plastic waste in a circular economy*, in *Plastic Waste and Recycling: Environmental Impact, Societal Issues, Prevention and Solutions*, T.M. Letcher, Editor. 2020, Elsevier: Oxford. p. 481-512.; Ellen Macarthur Foundation. New Plastics Economy. 27.05.2020]; Available from: https://www.ellenmacarthurfoundation.org/our-work/activities/new-plastics-economy; https://www.unido.org

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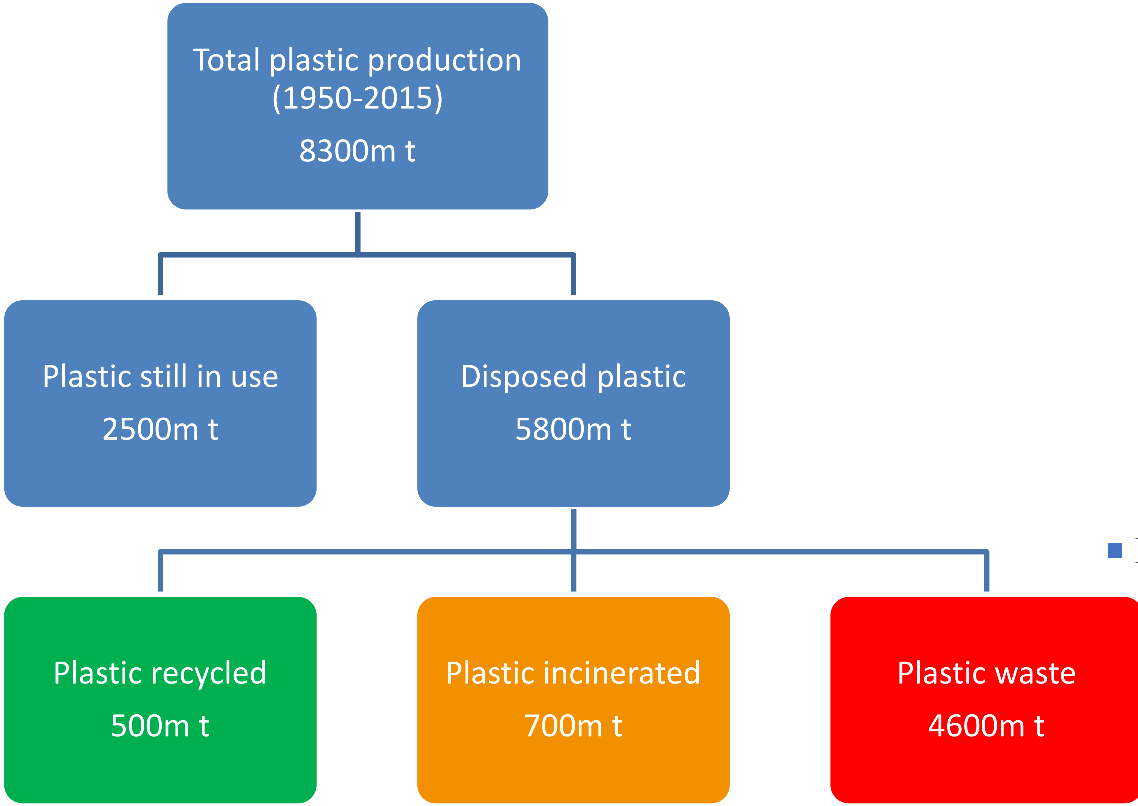
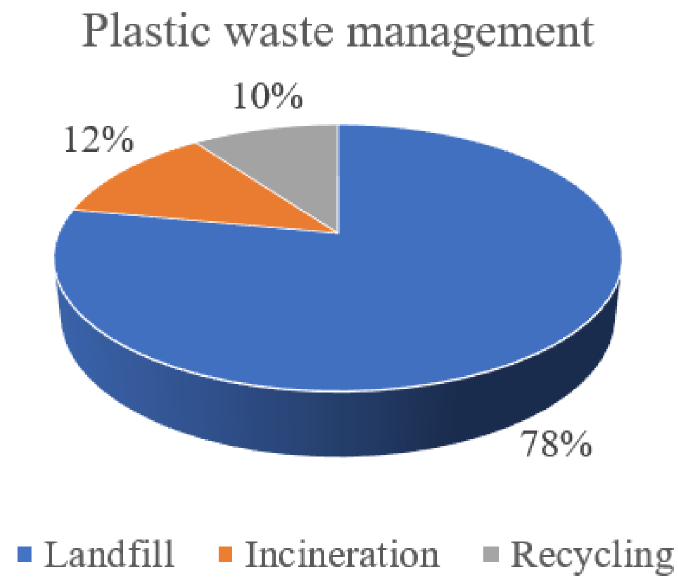
Life of Plastics Globally





https://www.nationalgeographic.com/news/2017/07/plastic-produced-recycling-waste-ocean-trash-debris-environment/

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Managing Plastics Waste

- Depletion of natural resources.
- Environmentally damaging
- Construction, management and operation requires high capital cost.
- The estimated cost from single-use plastics, together with those of the greenhouse gases emitted during production was $40 billion.

- Consider plastic a value product, rather than waste.
- Prevents depletion of natural resources.
- Enables sustainable plastic production.

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Polypropylene (PP)

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- the second most used commodity polymer
- global PP market, 2017, $80 bnpa, ~23% of the entire plastics market, expected to reach $133 bnpa by 2023

- carpet is a significant contributor to PP waste
- PP carpet, 17.6% of the PP product market, 45% of the global carpet market of $39.1 bnpa
- In the UK, ~400,000 t of waste carpet is produced each year, 66% of which ends up in land fill
- **an effective recycling system is required**

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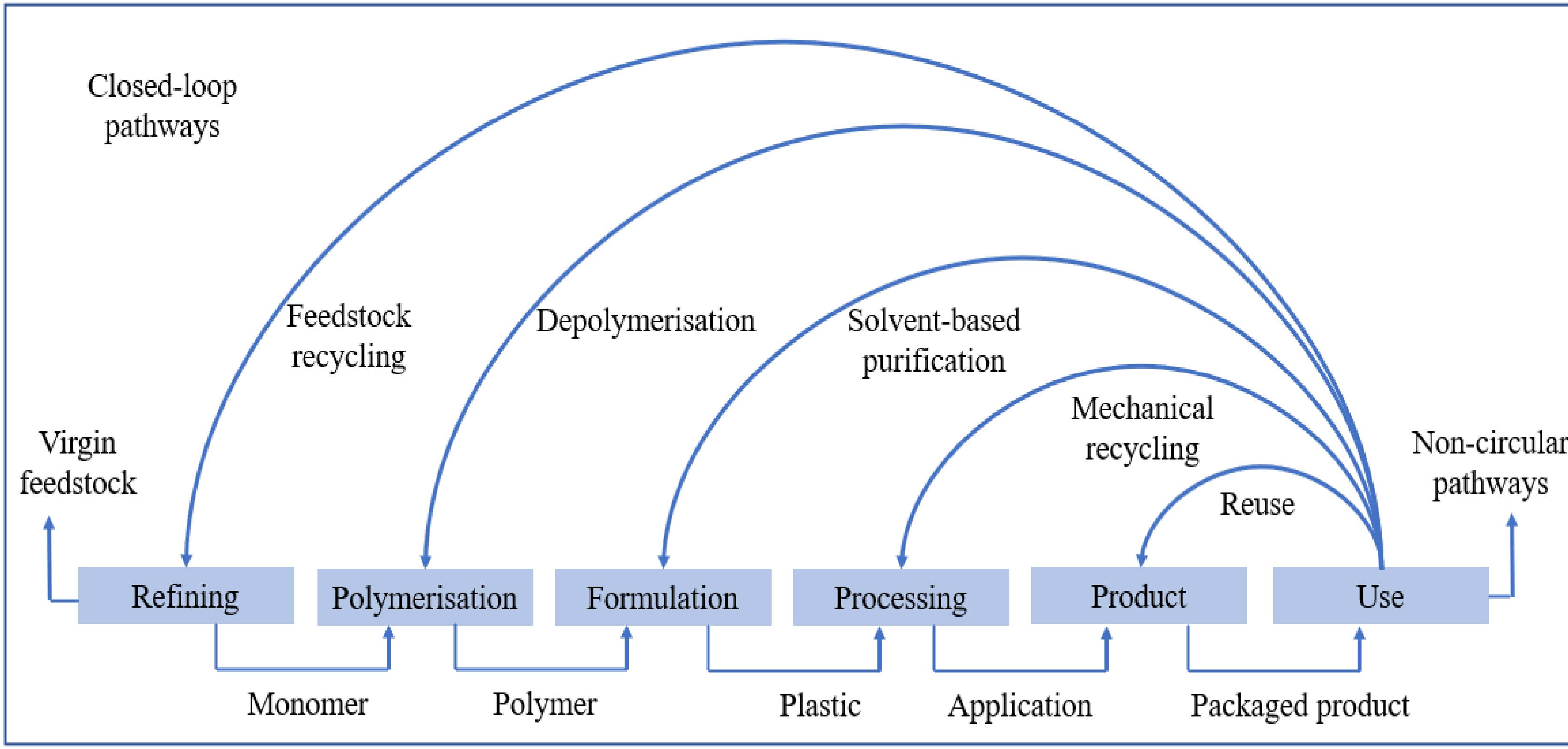
Solvent-based recycling



Overview of different loops for plastics in a circular economy

https://www.chemicalrecycling.eu/wp-content/uploads/2019/11/EuRIC_Position_paper_chemicalrecycling_2019-final-1.pdf

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Solvent-based recycling

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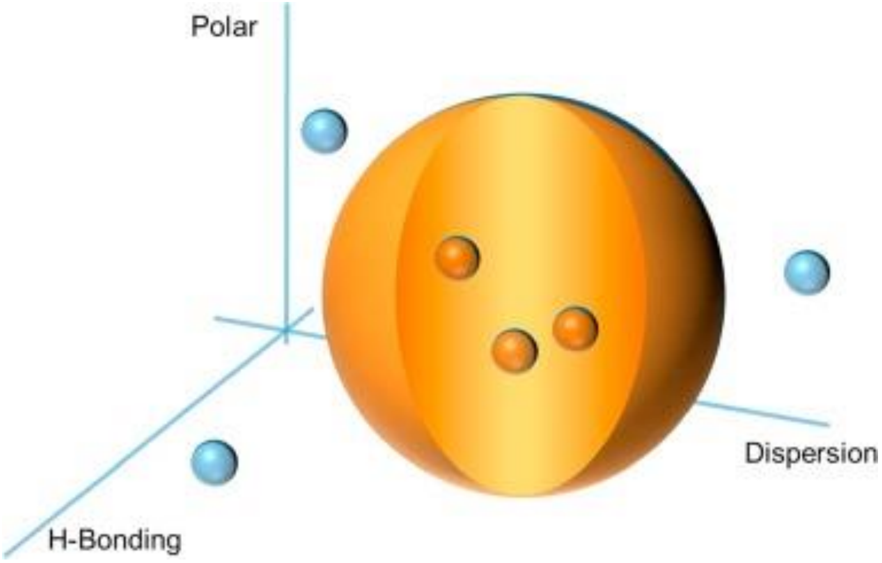
- Compared to other methods, recycling by solvent-based method (also called solvent extraction) gained importance as it has been especially proved to be successful in purification of recycled polymers.
- First studies about solvent-based recycling dates back to 1970s.
- The technique generally comprises the
  - dissolution
  - filtration for the removal of undissolved materials,
  - Precipitation in a nonsolvent/slow cooling
  - thorough washing and
  - drying.
- The solvent/non-solvent mixtures formed are separated by distillation for reuse.



Polymer Engineering & Science, 1976, 16(4): 246-251; American Chemical Society, 1992, 147-162. Journal of Applied Polymer Science, 2009, 114(1): 212-221; Advances in Polymer Technology, 1995, 14(3): 237-242; Conservation & Recycling, 1983, 6(3): 123-137; Resources, Conservation and Recycling, 1997, 20(1): 31-41; Advances in Polymer Technology, 1997, 16(4): 313-322; Journal of Hazardous Materials, 2007. 149(3): 536-542; Polymer Bulletin, 2009, 63(3): 449-465; Journal of Polymer Engineering, 2013, 33(5): 471-481; Chemosphere, 2018, 209: 707-720

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Solvent-based recycling

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The main advantages of this technique are

- the reduction of the volume of the plastics,
- removal of additives or impurities,
- the possibility of precipitating the polymer in different forms (granules, fibrils or powder) for further processing, and
- recovery of high quality polymers, which can be used for any kind of application, since the final product is of competitive quality compared with the virgin material.
- Besides, the value added during polymerisation is maintained during this recycling method as the polymer itself is obtained rather than monomers or some chemicals
- Moreover, it has the potential to deal with the mixtures of polymers based on the selective dissolution ability of the solvent used

Polymer Bulletin, 2009, 63: 449-465; Journal of Polymer Engineering, 2013, 33(5): 471-481; Conservation & Recycling, 1987, 10(4): 315-319.

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Solvent-based recycling

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Virgin Polymers	References
PP	Drain et al., 1983 Poulakis et al. 1997 Achilias et al., 2009 Murphy et al., 1979
PE	Poulakis et al., 1995 Achilias et al., 2007 Achilias et al., 2009 Papaspyrides et al., 1994
PET	Achilias et al., 2009 Poulakis and Papaspyrides, 2001
PS	Achilias et al., 2009 Kampouris et al.,1987 Kampouris et al., 1988
PVC	Achilias et al., 2009
PC	Achilias et al., 2009
PABS	Achilias et al., 2009

Products	References
PVC bottles	Kampouris et al., 1986
PS foam	Kampouris et al., 1987 Kampouris et al., 1988
Ldpe film from greenhouses	Papaspyrides et al., 1994
PET bottles for edible oil packaging	Poulakis and Papaspyrides, 1994
PP pipes	Poulakis and Papaspyrides, 1997
PC, PABS, PS from WEEE	Achilias et al., 2009

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ISOPREP project

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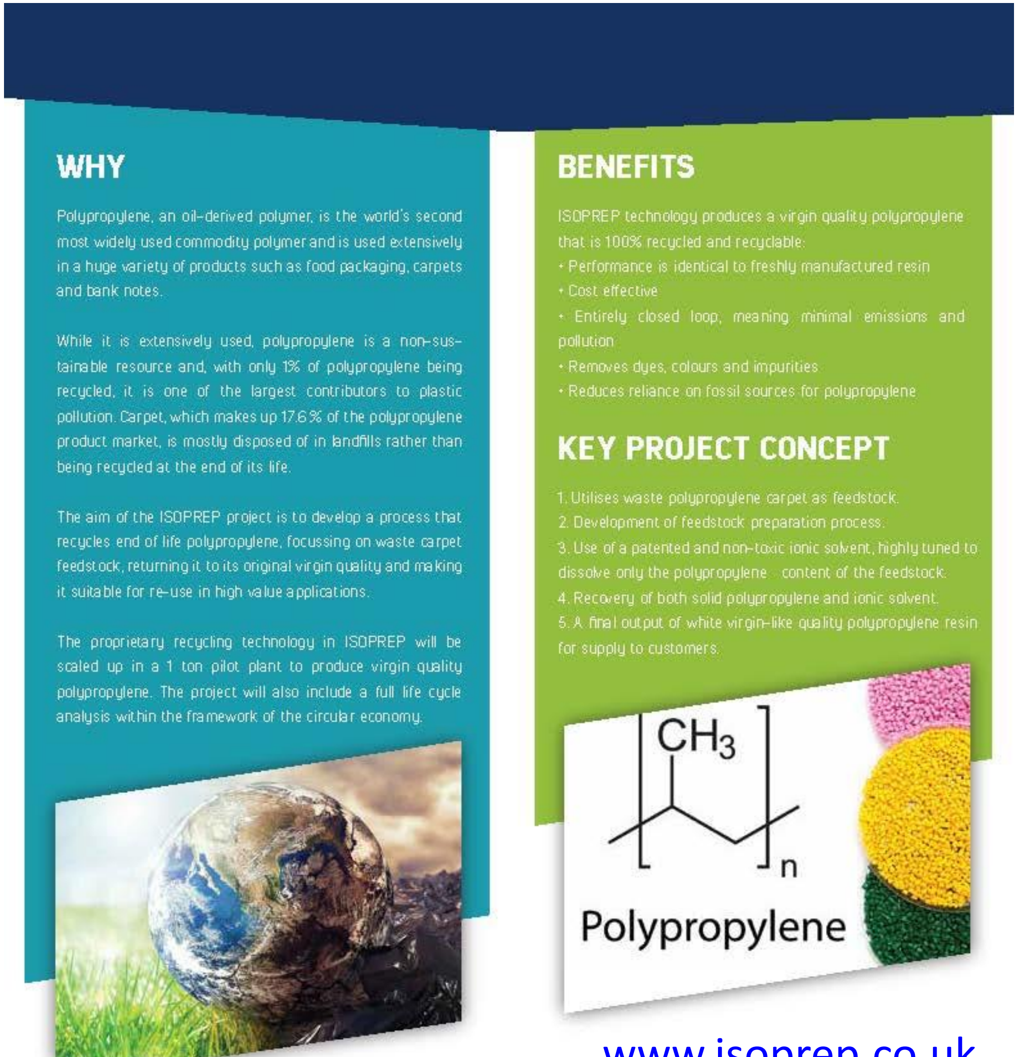

- proposes an innovative, alternative approach for the recycling end-of-life polypropylene products.
- uses proprietary ionic liquid to selectively dissolve polypropylene.
- will scale up the solvent based recycling technology.
- will include a full LCA, to determine commercial viability.
- will design a 1 tonne pilot plant
- aims to have a virgin quality polypropylene that is price competitive.

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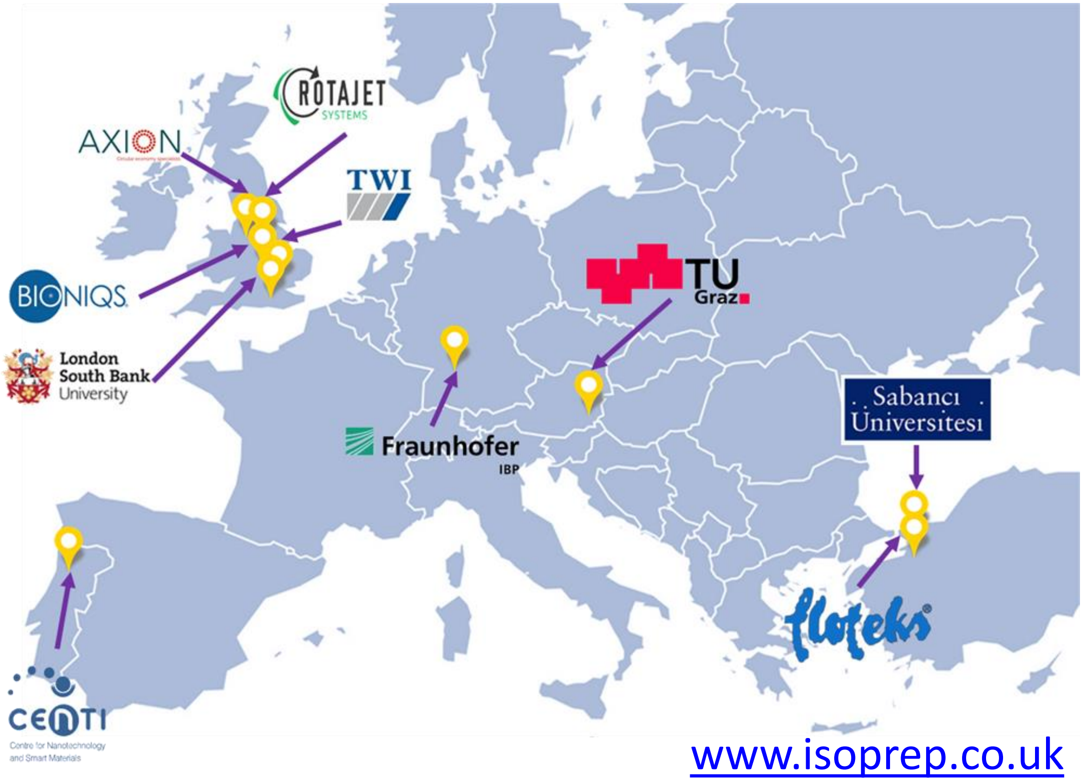
ISOPREP project

- is a EU Horizon 2020 programme funded project with a budget of € 6.3M.
- has a duration of 3 years (started in October 2018).
- led by TWI.
- includes 10 partners from 5 European countries.



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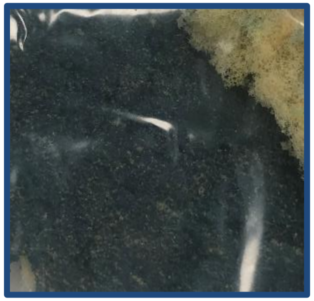
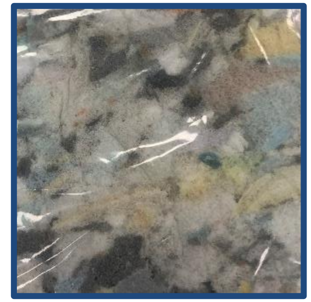
Waste carpet

Carpet Nr	PP	Wool	Jute	Cotton	PA	PET	PE	PAN	Backing
Ax-1-01	6.90	49.84	38.96	4.31					
Ax-2-01	5.45		11.38		83.17				
Ax-3-01						71.60	28.40		
Ax-4-01	4.51	75.92	19.57						
Ax-5-01	2.15					44.47			53.38
Ax-6-01	22.13				77.87				
Ax-6-02		46.27	43.43	10.30					
Ax-7-01	8.74		18.88		63.20	9.18			
Ax-7-02	7.00							93.00	
Ax-7-03	5.07	80.36	14.56						
Ax-7-04	10.19	89.81							
Ax-7-05	14.87	52.47							32.66
Ax-8-01	64.10					35.90			
Ax-8-02	46.85					37.92			15.24
Ax-9-01	82.45		13.07						4.47
Ax-9-02	87.68					3.91			8.40
Ax-10-01			45.12	9.55	45.34				
Ax-10-02	5.83		16.00		78.18				
Ax-11-01	50.30		41.03			8.67			
Ax-11-02	77.11		18.89			4.00			
Ax-11-03	77.86		16.94			5.20			
Ax-11-04	100.00								
Ax-11-05	72.43		21.62			5.95			
Ax-11-06	100.00								
Ax-11-07	75.63		15.89			8.48			
Ax-11-08	73.39		22.02			4.59			
Ax-11-09	100.00								

Backing materials in waste carpet



Backing Nr	Foam	Coating layer 1	Coating layer 2	PET (Paper Sticthing Yarn)	Metallized particle	Particle1	Particle2	Particle3	Particle4
Ax-12-01-B	LDPE	Paper							
Ax-12-02-B	PU	PET nonwoven	LDPE nonwoven						
Ax-12-03-B	PU	PET nonwoven							
Ax-12-04-B	PU	PET nonwoven	LDPE film		PET				
Ax-12-05-B	SBR								
Ax-12-06-B	PU	LDPE film	LDPE film						
Ax-12-07-B	PU	Paper	LDPE film	PET (Paper Sticthing Yarn)					
Ax-12-08-B	SBR	Paper		PET (Paper Sticthing Yarn)					
Ax-12-09-B	PU	PET nonwoven				PU	PU	PE	PU

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Main components of waste carpet

Photographs of the main carpet components:

(a) Jute
(b) Cotton
(c) PET
(d) SBR
(e) Wool
(f) PAN
(g) PP
(h) PET nonwoven
(i) PU
(j) SBR
(k) Paper
(l) PA

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Leaching behaviour of components

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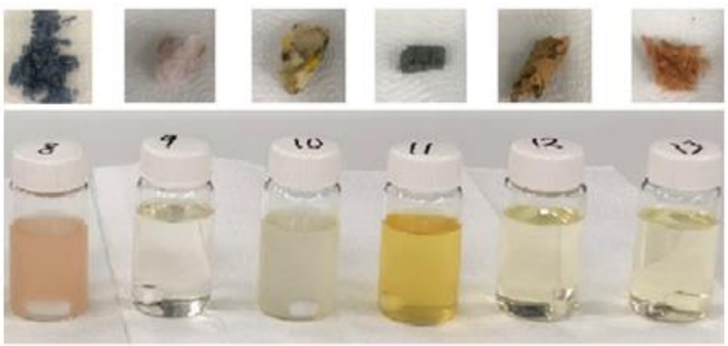
(a) (b) (c) (d) (e) (f) (g)



(h) (i) (j) (k) (l) (m)

Photographs of the tested carpet components and the solvents recovered after the leaching process performed at 110°C for 6 hours:
(a)Jute, (b)Cotton, (c)PE, (d)PET, (e)SBR, (f)Wool, (g)PAN, (h)PP, (i)PET nonwoven, (j)PU, (k)SBR, (l)Paper, (m)PA

Material	Leaching (110°C, 6h)		Suspended (Centrifugation)	Dissolved (Precipitation&Centrifugation)
	Weight Loss (%)	D/S	Possible structure of the suspended content	Structure of dissolved content
Jute	-8.05	D	*	Jute and/or styrenic polymer
Cotton	-9.04	D/S	Defoamer, poly(propylene:ethylene)	Verbenone
PE	dissolved	S	*	*
PET	-1.10	D	*	Smithsonite, calcium carbonate
SBR	-6.76	D/S	*	Poly(styrene-co-butadiene)
Wool	-8.95	D/S	Silicone antifoam, surfactants, poly(dimethylsiloxane)	Neodecanoic Acid
PAN	-2.84	D	*	Poly(ethylene-co-vinyl acetate)
PP	-7.65	D	PE, tritriacontane	Erucic acid; (Z)-13-Docosenoic acid
PET nonwoven	-1.89	D	*	Triacontane, PE, defoamer, EVA
PU	-26.08	D/S	Wax dispersion, PE, paraffin wax, defoamer	Neodecanoic acid
SBR	-17.16	D/S	Poly(dimethylsiloxane), surfactant, antifoam	Poly(dimethylsiloxane), antifoam H-10
Paper	-7.16	D	*	Defoamer, PE, paraffin wax blend
PA	-4.22	D	*	Poly(ethylene-co-vinyl acetate)
PU (with PE films)	-23.59	D/S	PE, tritriacontane	Glycol
PP	-2.49	D/S	*	Polypropylene + poly(ethylene:propylene)

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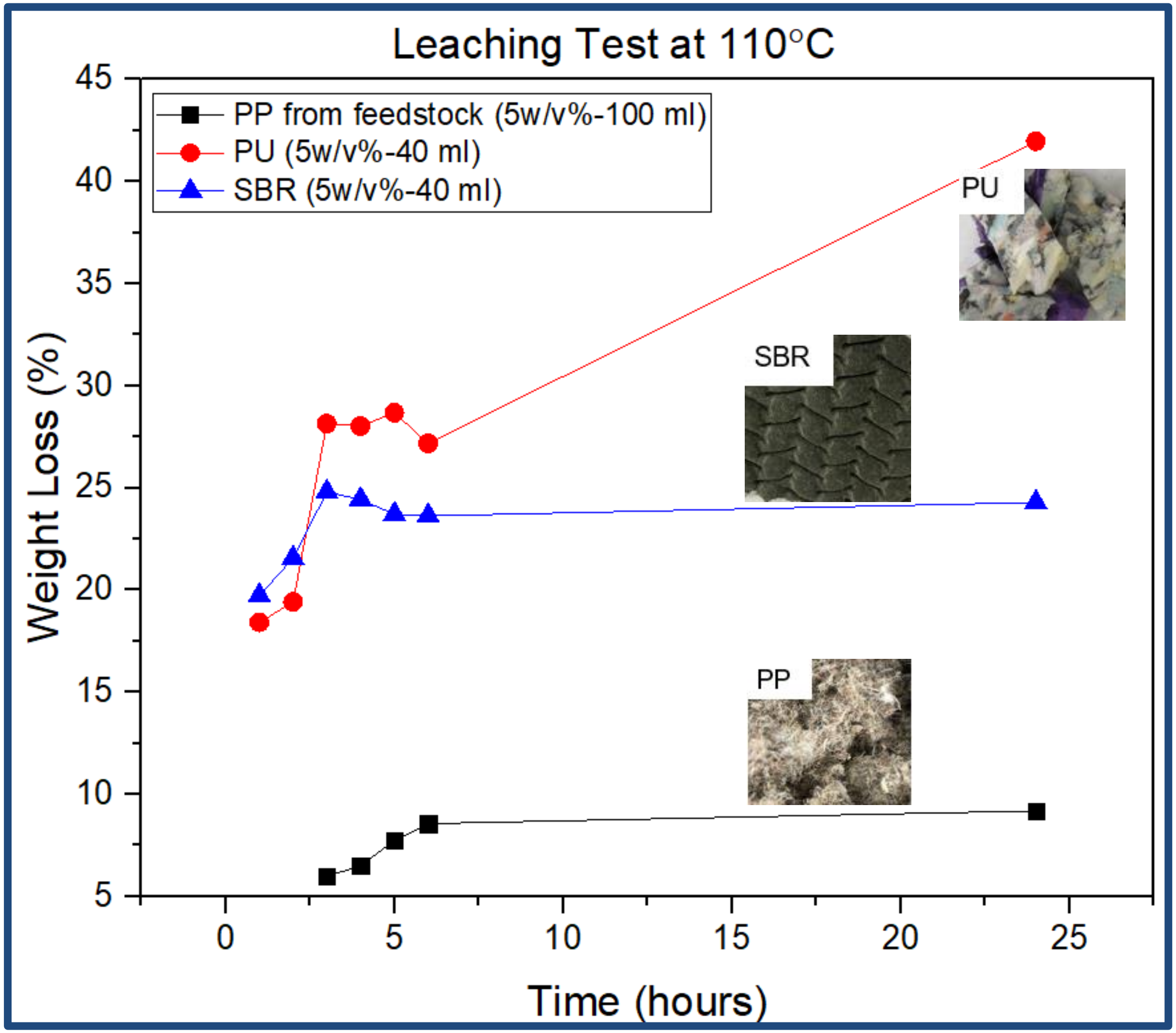
Leaching behaviour of components



solvents after 24h leaching	Solid materials detected by FTIR
PU 	✓ Velvetrol 77-70, ✓ Shell 700, ✓ Kessco PEG 1000 Hexatriacontane, Polyethylene, ✓ Calcium stearate
SBR 	✓ Styrene homopolymer ✓ Kristalex S140 ✓ 2,3-difluorophenol ✓ Poly(styrene-co-allyl alcohol) ✓ Ropaque OP-62
PP 	✓ PP

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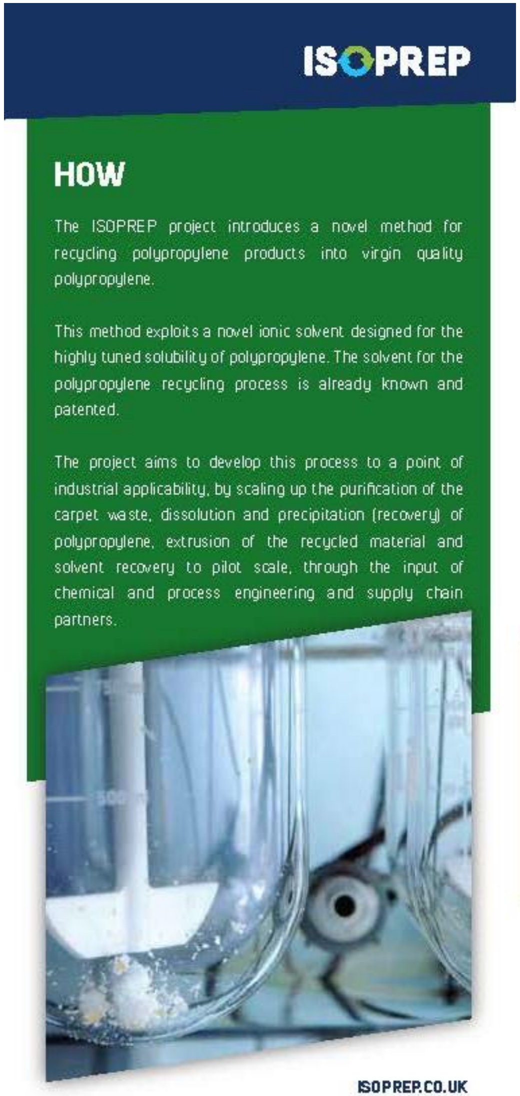
Method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HOW

The ISOPREP project introduces a novel method for recycling polypropylene products into virgin quality polypropylene.

This method exploits a novel ionic solvent designed for the highly tuned solubility of polypropylene. The solvent for the polypropylene recycling process is already known and patented.

The project aims to develop this process to a point of industrial applicability, by scaling up the purification of the carpet waste, dissolution and precipitation (recovery) of polypropylene, extrusion of the recycled material and solvent recovery to pilot scale, through the input of chemical and process engineering and supply chain partners.

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- A recycling process was developed using a proprietary solvent enabling the selective dissolution and recovery of PP.
- Starting from the pre-processes to increase the PP content in the waste carpet feedstock materials, the dissolution, dye removal, and precipitation processes were developed and optimized in order to obtain high purity recycled PP along with solvent recovery processes.

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Conclusions

- The characterization techniques confirmed that high-purity recycled PP polymer with properties identical to PP polymer produced from petroleum derived products was obtained.
- The detailed analyses showed that the newly developed recycling process had no effect on the chemical structure of PP.
- The recycled PP was similar in structure to pure PP pellets without any impurities. Additionally, it was free from solvent used in the recycling process.
- All thermal transitions as well as thermal decomposition behaviour of the recycled PP polymer were identical to that of pure PP polymer.

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Conclusions

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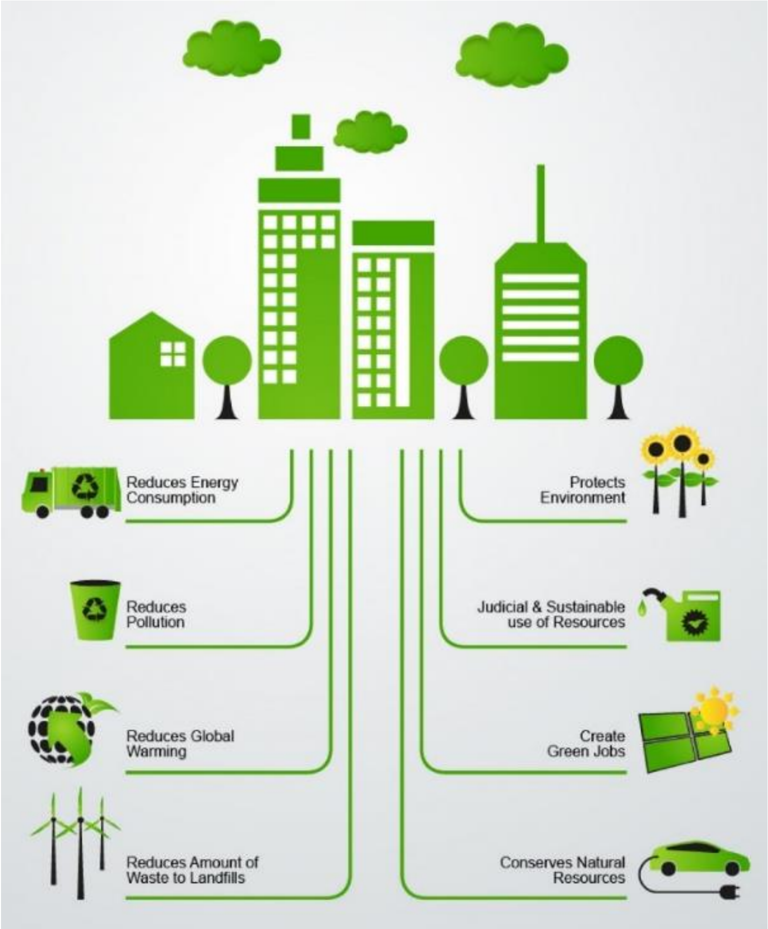
The new recycling process that is viable within circular economy is expected to

- contribute to the recycling of the end-of-life PP products,
- help avoid the environmental pollution,
- reduce the reliance of PP production on petroleum-based resources, and
- decrease CO_2 emissions.



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