IKK
Institut für Kunststoff- und Kreislauftechnik
Prof. Dr.-Ing. Hans-Josef Endres

ARBURG Technology Days 2022

CIRCULAR ECONOMY - CONCEPTS FOR SUSTAINABLE PLASTIC PARTS MADE FROM RECYCLATES

Prof. Dr.-Ing. Hans-Josef Endres

Loßburg, June 22 - 24

Leibniz Universität Hannover
Produktionstechnisches Zentrum Hannover

Scope

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- When is a recyclate a recyclate?
- How much recyclate must be in there so that a recyclate can also be called as recyclate?
- Do all recycling processes lead to the same result?
- Which recycling processes will have a quota effect in the future, e.g. for the plastic tax?
- Is recycling sustainable?
- Are there sufficient standards and norms in the recycling sector?
- Do we have enough high quality) recyyclates?
- Where are the current bottlenecks?
- What are mass-balanced recyclates or bioplastics?
- Can you prove recycling?

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Professional Career


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RUHR UNIVERSITÄT BOCHUM RUB

1991 Dipl.-Ing.

1995 Dr.-Ing.

thyssenkrupp

1991 - 1999
Area Manager

HOCHSCHULE HANNOVER UNIVERSITY OF APPLIED SCIENCES AND ARTS
Fakultät II Maschinenbau und Bioverfahrenstechnik

1999
Professor

IfBB Institute for Bioplastics and Biocomposites

2011
Institute Director

Fraunhofer HOFZET WKI

2013
Head of Department

IKK Institut für Kunststoff- und Kreislauftechnik
Prof. Dr.-Ing. Hans-Josef Endres

2019
Institute Director

Gottfried Wilhelm Leibniz University Hannover (LUH)

Facts & Statistics

Founded
- 1831
- T9 German University

- **Overall Budget (2019)**
  - 266.7 MEUR
- ***Students (2019/20 WiSe)***
  - *30.196*
- ***Degree Courses***
  - 84 Degree Programs
  - 9 Faculties
- **Staff**
  - 5.138 Staff
    - 3.320 Research and Teaching Staff incl. 348 Professors
    - 1.744 Technical and Administrative Staff
    - 74 Apprentices
- **Buildings**
  - 325.720m² Floor Space
  - 167 Buildings


© Daniel Vogl, LUH

Main Building of the Leibniz University of Hannover

Faculty of Mechanical Engineering
Facts & Statistics

IKK Institut für Kunststoff- und Kreislauftechnik

- 20 Institutes
- 900 Employees
- Research Funding: 75 Mio Euro p.a.
- 75 Doctoral Theses p.a.
- 5.000 Students

Hannover Center for Production Technology (PZH) opened in 2014

Faculty of Mechanical Engineering

Mechanical Engineering Campus of Leibniz University Hannover (2020)

Institute of Plastics and Circular Economy IKK
Research focus

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Color batch for thermoplastics

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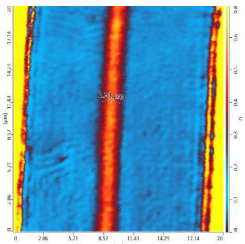

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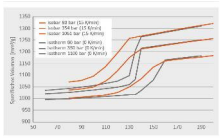

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Plastics Technology and Recycling | **Plastics Analytics**

IKK

Sustainability Assessment | **Material Testing**

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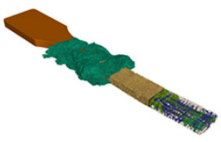

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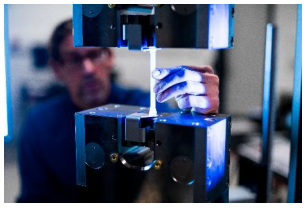

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Plastics as amazing, innovative, unique Materials

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Plastics – good, bad or both?

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Source: www.uunsplash.com

Costs - Performance - Sustainability

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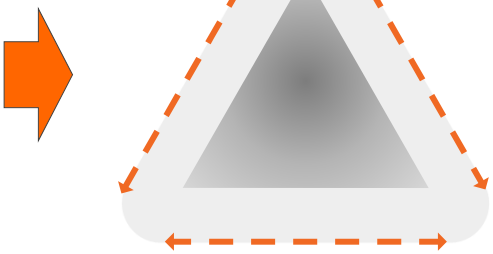
Costs ← – – → Performance



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Approaches for the plastic industry to become CO_2-neutral

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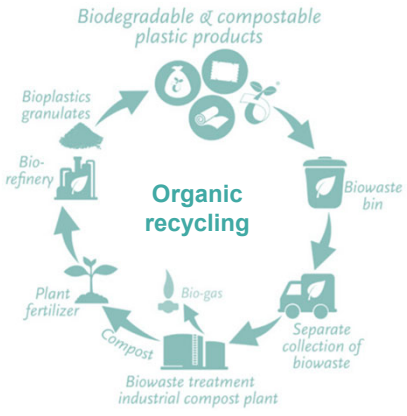
I



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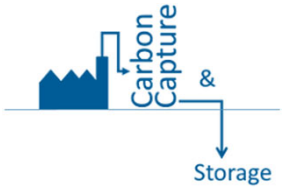
II

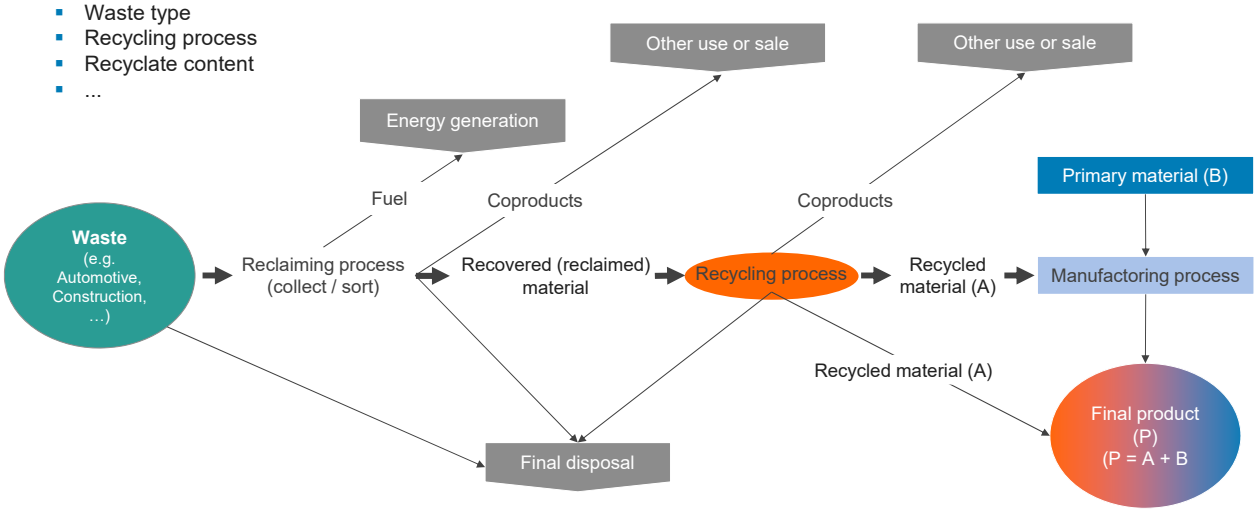
III

Capture and use of CO_2 from the atmosphere



Recycling system
Simplified diagrammatic representation

- Definition of recyclate with regard to
  - Waste type
  - Recycling process
  - Recyclate content
  - ...



ISO 14021:2016 - Environmental labels and declarations – Self-declared environmental claims (Type II environmental labelling)

Recyclate
Definition with regard to the waste type

Input must be declared as waste prior to recycling

Types of waste (ISO 15270:2008)

- **Post-consumer**: material, generated by the end-users of products, that has fulfilled its intended purpose or can no longer be used (including material returned from within the distribution chain)

- **Post-Industrial**: material diverted during a manufacturing process
  - NOTE 1 This term **excludes** re-utilized material, such as rework, regrind or scrap that has been generated in a given process and is capable of being reclaimed within that same process
  - NOTE 2 The term "**post-industrial material**" is sometimes used synonymously

Recyclate
Definition with regard to the waste type as input material

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- **Post-industrial materials**

Input material from **production**

- at the plastics **producer** (e.g. conversion of machine / change of recipe, start, stop and conversion processes, etc.)
  at the plastics **processor/converter** (e.g. punching grids / slugs / sprue waste / film edge strips, material from production changeovers)

Input material from **faulty production**

- at the plastics **producer** (e.g. off-spec goods, NT goods)
  at the plastics **processor/converter** (e.g. off-spec goods, NT goods)

Input material from **fabrication at the plastics processor/converter** (e.g. offcuts / remaining pieces / returns)

Input material from **fabrication at a company in the supply chain** (e.g. external confectioner and not end-consumer)

- **Post-consumer materials**

Input material from the **supply chain** (e.g. customer complaints or stock that has become unsaleable by retailers)

Input material from used **industrial or transport packaging** (e.g. drums or IBCs from chemical industry, stretch films from retailers)

Input material from **used packaging (e.g. yellow bag)**

Input material from **used plastic products from consumers**

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Recyclate
Definition with regard to the waste type

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  - NOTE 2 The term "**post-industrial material**" is sometimes used synonymously

- What is „that same process"?
  - Same production line, same product, same company?
- Which materials can be used for the manufacture of post-consumer recyclates (PCR) and post-industrial recyclates (PIR)?
- Which materials cannot be used for the manufacture of recyclates?

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Recycling system
Simplified diagrammatic representation

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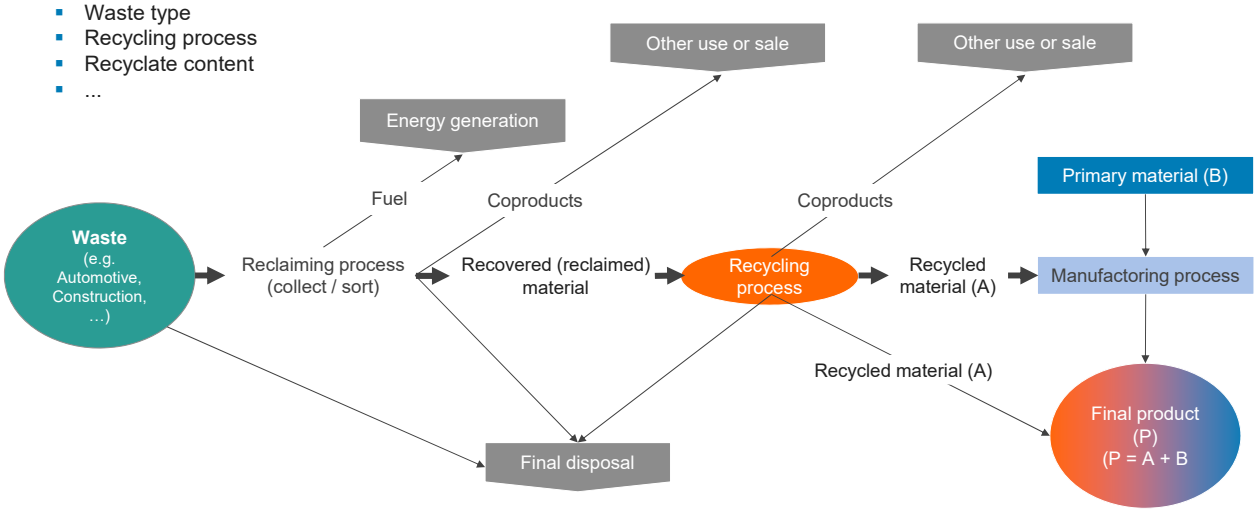
  - Recyclate content
  - ...



ISO 14021:2016 - Environmental labels and declarations – Self-declared environmental claims (Type II environmental labelling)

Recycling processes

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Recycling approaches	Process / procedure	Output
Enzymatic	Specific degradation of polymer substances	e.g. polyester recovered from blended fabrics through enzymatic degradation of cotton or PUR
Biological / organic	Biological polymer degradation	CO_2, H_2O, methane, biomass
Energetic	Incineration with energy use / recovery	energy, (CO_2, H_2O, ash)
Mechanical (95%)	Mechanical crushing	Regrind (composition as input stream)
	Pre-treatment of the input stream with subsequent extrusion / granulation	Granulate: regranulate
	Pre-treatment of the input stream with subsequent extrusion / granulation and with the addition of further material components	Granulate: recompound / regenerate
Solvent-based (3-4%)	Selective dissolution and recovery of individual polymer types, i.e. change of physical state without changing the polymer structure	Polymers of one polymer type (e.g. PE dissolution with hexane or decalin, PS in toluene)
Chemical (2-3%) Thermolysis	Pyrolysis	Pyrolysis oil, syngas and carbonised char
	Gasification	High calorific value syngas and char
	Liquid gas hydrogenation	Highly saturated liquid hydrocarbons
Chemical (2-3%) Solvolysis/ Chemolysis	Methanolysis	PET: dimethyl terephthalate
	Glycolysis	PET: glycolysate bis(hydroxyethyl) terephthalate, various acids, esters, polyols
	Hydrolysis	PET: Terephthalic acid
	Ammonolysis, Aminolysis	Amides, ethylene glycol

Source: H.-J. Endres et. al: Recycling and circular economy are not always the same, Polyproblem-Report 2 / 2020, Röchling Stiftung, modified

Assessment of processes - mechanical versus chemical recycling

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Property	Mechanical Recycling	Chemical Recycling
Technical requirements for infrastructure / processes	+ (low)	- (high)
Possibility of decentralized processing	+ (possible)	- (currently technically challenging and uneconomical)
Requirement on quality for input stream	- (medium - high)	0 (low - medium)
Quality of output material	0/- (proportional to the quality of input material. Moderate quality improvement using process parameters and additives is possible and is inversely proportional to the technical expense)	+ (very high)
Food regulatory approval of the output	0 (in special cases PE (and HDPE) possible)	+ (high)
Possibility of multiple recycling	0 (limited)	+ (high)
Industrial maturity	+ (high)	0 (depending on process, not fully mature)
Cost	+ (low)	- (high)
Environmental assessment / Quality of data	+ / LCA data gaps	0 / almost no data

Source: H.-J. Endres: Recycling and circular economy are not always the same, Polyproblem-Report 2 / 2020, Röchling Stiftung, modified

Recycling system
Simplified diagrammatic representation

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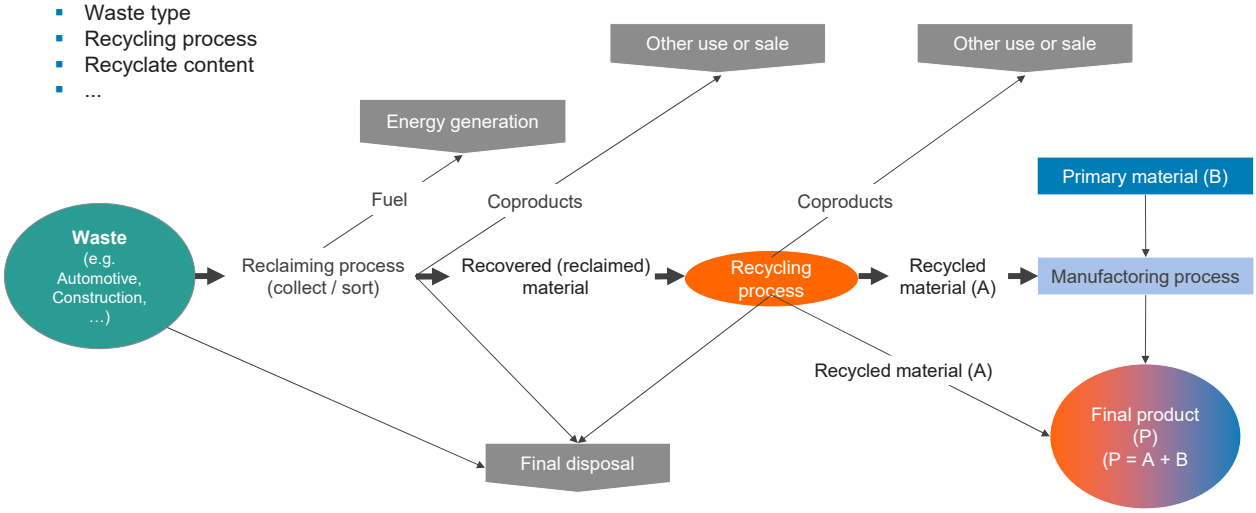
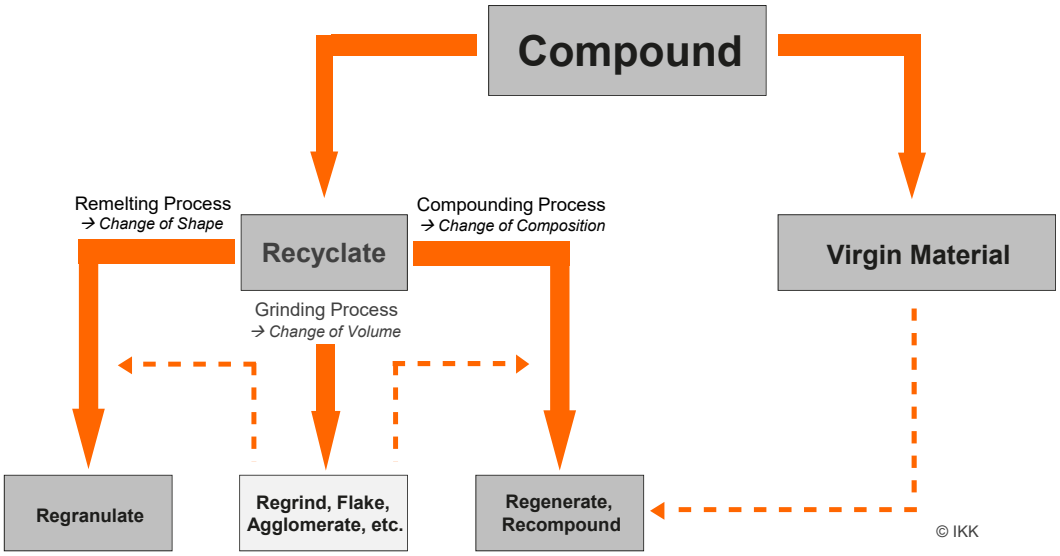


ISO 14021:2016 - Environmental labels and declarations – Self-declared environmental claims (Type II environmental labelling)

Mechanical Recycling Processes



Recycle
Definition with regard to content / characterisation

General information

- There is no regulation regarding min. recycled content in plastic mixtures
  - Plastic mixtures composing of virgin and recycled plastic may also be called recycle
- There is no regulations regarding recycling process, e.g.
  - Mechanical recycling vs chemical recycling

Polymer-specific standards for recycle characterisation

- Recycle content
- Other polymers
- Fillers
- Additives

EN 15345, DIN SPEC 91446

Recycled content in product (X %) $= \frac{mass\ _{recycle\ in\ product}}{total\ mass_{product}} * 100$

but EN 17615 (fprEN)

Recycled content in product (X %) $= \frac{mass\ _{recycled\ plastic\ in\ product}}{total\ mass_{product}} * 100$

Characterisation of Polypropylene (PP) recycles DIN EN 15345

Property	Uni	Test method
Required data		
Color		Visual examination
Density	kg/m³	EN ISO 1183-1
Impact strength	kJ/m²	EN ISO 179-1,-2 or EN ISO 180
Melt mass flow rate	g/10 min	EN ISO 1133
Form		Visual examination
Optional data		
Ash content	%	EN ISO 3451-1
Bulk density	kg/m³	Annex A
Other polymers	%	Thermal analysis / IR
Bending properties	MPa	EN ISO 178
Filtration grade	µm	Mesh size
Recycled content	%	EN 15343
Yield stress	%	EN ISO 527-1,-2
Elongation at break	%	EN ISO 527-1,-2
Content of volatiles	5	EN 12099, etc.

Recycled material: definition by content, using the polymer-specific standards

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- Legend: M – mandatory (gefordert), O - optional

Property	Definition process	DIN EN 15342 PS	DIN EN15344 PE	DIN EN 15345 PP	DIN EN 15346 PVC	DIN 15348 PET
Original use	To be definded by supplier	O				
Form	Visual examination	M	M	M	M	M
Recycled Content	EN 15343			O		
Color	Visual examination	M	M	M	M	M: Visual examination O: EN ISO 11664-4
Teilchengröße	ISO 22498	M: Verfahren entsprechend der Teilchenart und dem Korngrößenbereich	M			
Korngrößenverteilung	Normspezifisches Verfahren				M: Anhang D und E	M: max. Korngröße
Schüttdichte	Normspezifisches Verfahren	O: Anhang A	M: Anhang: B	O: Anhang A	M: Anhang B	
Dichte	EN ISO 1183	O: EN ISO 1183-1 oder Verfahren A	O	M: EN ISO 1183-1 oder Verfahren A	O: EN ISO 1183-1 oder Verfahren A	
Feinkornanteil	Normspezifisches Verfahren					M Anhang A
Filtrationsgrad	Maschenweite	O	O	O		
Filtrierfähigkeit	Normspezifisches Verfahren					O: Anhang E
Schmelze-Massenfließrate	EN ISO 1133	M: EN ISO 1133, Bedingung H	M	M: EN ISO 1133, Bedingung M		O: ISO 1133-2
Grenzviskosität (IV)	ISO 1628-5					O
Trockenfließrate	EN ISO 6186				O	
Vicat-Erweichungstemperatur	EN ISO 306	M: EN ISO 306, Verfahren A			O: EN ISO 306, Verfahren B50	
Wärmebeständigkeit	ISO 182-1, EN ISO 182-2, -3, -4				O	
Schlagfestigkeit	EN ISO 179-1, -2, EN ISO 180	M	O	M		
Streckspannung	EN ISO 527-1 oder -2	O	O	O	O	
Bruchdehnung	EN ISO 527-1 oder -2	O	O	O	O	
Biegeeigenschaften	EN ISO 178	O		O		
Härte	ISO 868				M (bei PVC-P)	
Contamination with other polymers	FT-IR or DSC		M (PP and others)	O		
Vorhandensein modifizierter Zusätze	Vom Lieferant anzugeben	O				
Fremdstoffe/Verunreinigungen	Normspezifisches Verfahren		O: Verfahren A, B, C oder D		M: Anhang C	
Gehalt an flüchtigen Bestandteilen	Normspezifische Vorgabe	O: Massenverlust bei 200 °C		O: EN 12099 oder eine andere	O: EN ISO 1269	
Restfeuchte/Wassergehalt	EN 12099	O	O		O	M: Anhang B oder EN ISO 15512
Aschegehalt	EN ISO 3451	O	O	O	M: EN ISO 3451-5 oder Verfahren A	
PVC-Gehalt	Normspezifisches Verfahren					M: Anhang C
Polyolefin-Gehalt	Normspezifisches Verfahren					M: Anhang C
Sonstiger Restgehalt						O: Analyse anhand eines geeigneten Verfahrens: FT-IR, DSC, XRF,...
Alkalität	Normspezifisches Verfahren					O: Anhang D
Verarbeitungstauglichkeit von PVC-Rezyklaten – durch Kalandern / – durch Extrusion	Normspezifisches Verfahren				O: Anhang F / Anhang G	

(*for more info s.* H.-J. Endres, M. Shamsuyeva (2020): Kreislaufwirtschaft braucht bessere Standards - Standards und Qualität von Kunststoff-Rezyklaten - eine Bestandsaufnahme, Plastverarbeiter 6)

DIN SPEC 91446 „Classification of recycled plastics by Data Quality Levels for use and (digital) trading”

IKK Institut für Kunststoff- und Kreislauftechnik

Waste characterisation → Classification of recycled plastics by DQL → Product data sheet and label

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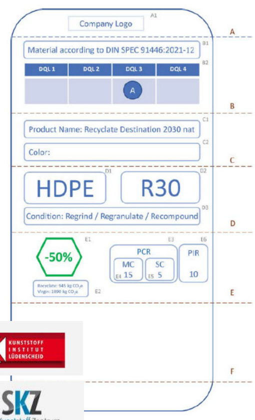
	Data Quality Levels			
	1	2	3	4
Information	3	11	12	14
Property	0	3	5	10
Optional characteristics	22			



* Initiator
** Consortium leader

cirplus, IKK Institut für Kunststoff- und Kreislauftechnik, DerGrünePunkt, REMONDIS, VDMA, BDE, Institut für Kunststoffverarbeitung, Kunststoff Institut Lüdenscheid, TOMRA, STEINERT, MKV, Materialis, greiner packaging, POLIFILM, KraussMaffei, SKZ Das Kunststoff-Zentrum

DIN SPEC 91446 – Data Quality Levels for Recyclates

IKK Institut für Kunststoff- und Kreislauftechnik

Information	Example	DQL 1	DQL 2	DQL 3	DQL 4
Material type	PE, PP, PET, ...	X	X	X	X
Recycled content according to Clause 6	X %	X	X	X	X
Packaging	Octabins, bagged goods, bale goods, silo	X	X	X	X
Filler content	Mineral X %, glass fibres X %		X	X	X
Color (without measurement)	Black, natural, white		X	X	X
Recycling method	Information about a mechanical recycling process, solvent-based process, etc.		X	X	X
Condition	Agglomerate, flake, regrind, regenerate, regranulate		X	X	X
Lot number	Given on the packaging or certificate of analysis		X	X	X
Certificate of analysis	DIN EN 10204, 3.1		X	X	X
Source	Post-consumer, post-industrial		X	X	X
Content of other plastics	Data from the sorting process, FTIR, DSC (DIN EN ISO 11357-1, DIN EN ISO 11357-2, DIN EN ISO 11357-3)			X	X
Trade name of the compound or product	(not necessarily a registered trade mark)			X	X
DIN EN ISO 9001 certification of the supplier	or other standards, that include DIN EN ISO 9001				X
Original use of the material	bottles or trays, blow molding or injection molding, description of waste, mixed waste				X

Property	Examples for standards	DQL 1	DQL 2	DQL 3	DQL 4
Viscosity (MVR/MFR, IV, VN)	DIN EN ISO 1133 series, DIN EN ISO 307, (DIN EN) ISO 1628 series		X	X	X
Ash content	(DIN EN) ISO 3451 series, DIN EN ISO 1172		X	X	X
Residual humidity	DIN EN ISO 15512, DIN EN 13267, calibrated IR scale		X	X	X
Density	DIN EN ISO 1183 series			X	X
Bulk density	DIN EN ISO 60			X	X
Heat deflection temperature or Vicat softening temperature	DIN EN ISO 75 series, DIN EN ISO 306				X
Particle size distribution	DIN 53477 or average grain size and shape of the granulate				X
Material identification (FTIR or DSC)	IR (data base comparison), DSC (DIN EN ISO 11357-1, DIN EN ISO 11357-2, DIN EN ISO 11357-3)				X

… + different optional characteristics

DIN SPEC 91446 – Data Quality Levels for Recyclates

IKK Institut für Kunststoff- und Kreislauftechnik

… + different optional characteristics

Optional characteristic	Example (standards)	Property	Information
Hardness	DIN EN ISO 868, DIN ISO 48-4, DIN EN ISO 2039-1, DIN EN ISO 2039-2	X	
Color (measurement)	DIN EN ISO 3668, DIN 53236	X	
Tensile properties	DIN EN ISO 527-1, DIN EN ISO 527-2	X	
Bending properties	DIN EN ISO 178	X	
(notched) impact resistance	DIN EN ISO 179-1, DIN EN ISO 180	X	
Flammability	UL 94, DIN 75200	X	
Odor or emission measurements	VDA 270, VDA 277, VDA 278	X	
Chemical resistance	DIN EN ISO 22088 series	X	
Shear curve	ISO 11443	X	
Content of contaminants in the plastic waste feedstock for recycling	Information from the specification of plastic waste as feedstock for recycling		X
Melt filtration	Mesh size, kind of filter		X
Details of the washing process of the recycling process	Cold/hot wash		X

Optional characteristic	Example (standards)	Property	Information
Further details about the recycling process	drying, density separation, dedusting		X
Known additives	Stabilizers, plasticizers, flame retardants		X
Details of the colorant	Influence on the recyclability (e.g. carbon black)		X
Content of contaminants in the compound	Metals, minerals, paper DIN CEN/TS 17627		X
Intended or non-intended use of the material	Intended use: injection moulding, blow film Non-intended use: extrusion		X
Intended market	Food packaging, automotive, IEEE		X
CO_2 equivalents	DIN EN ISO 14067		X
Recyclability			X
Traceability	Digital code, sorting aid/anorganic and organic tracers		X
Lot size	X tons		X

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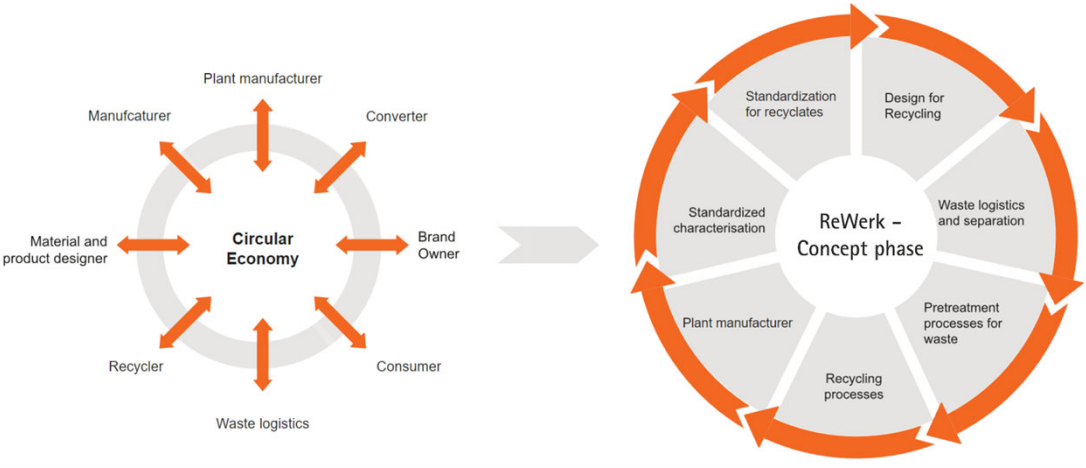
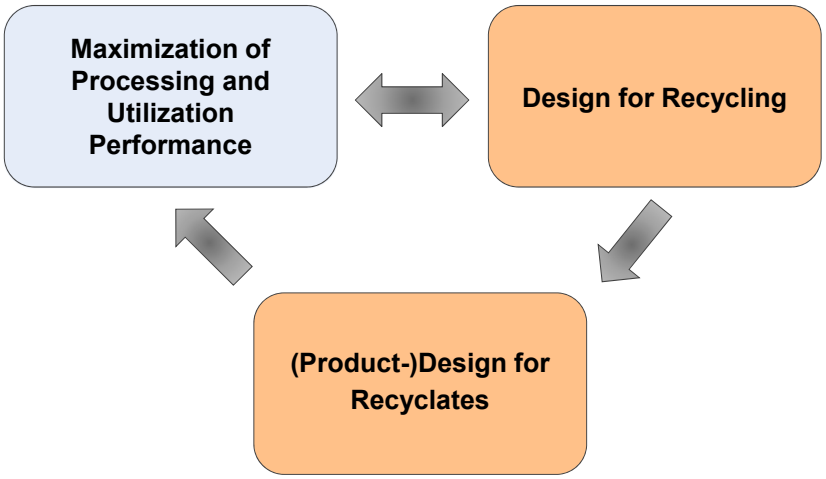
Slide 24 | IKK - Institute of Plastics and Circular Economy

All stakeholders are needed to establish circular economy

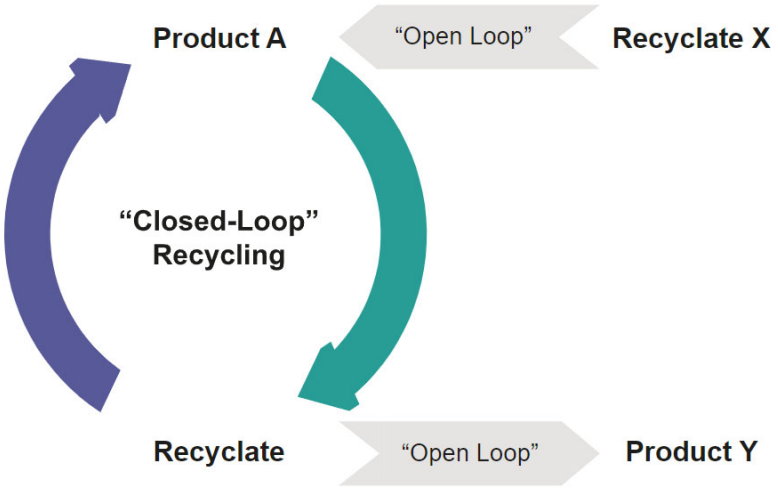
- Instead of individual activities, new partnerships along the entire "recycling value chain" are needed to establish a circular economy



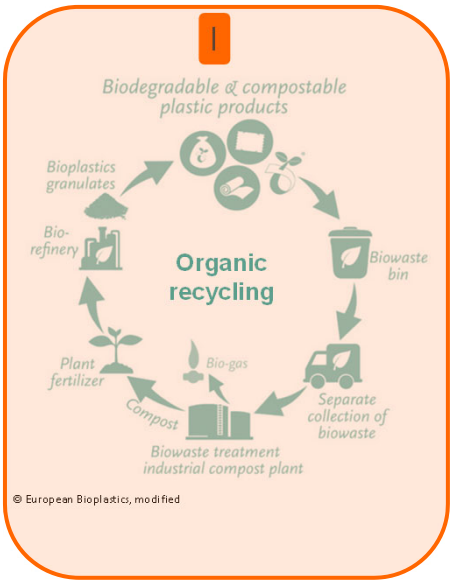
Design for Recycling

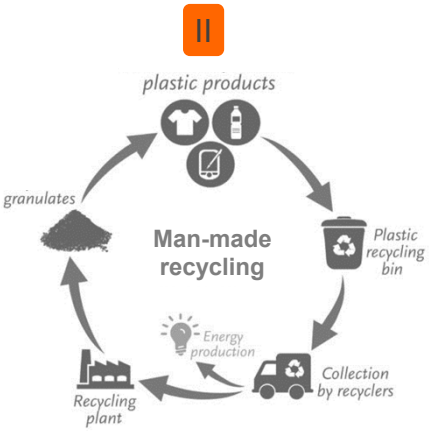


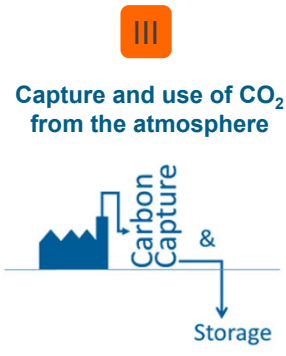
Open and Closed Loop Recycling Approaches



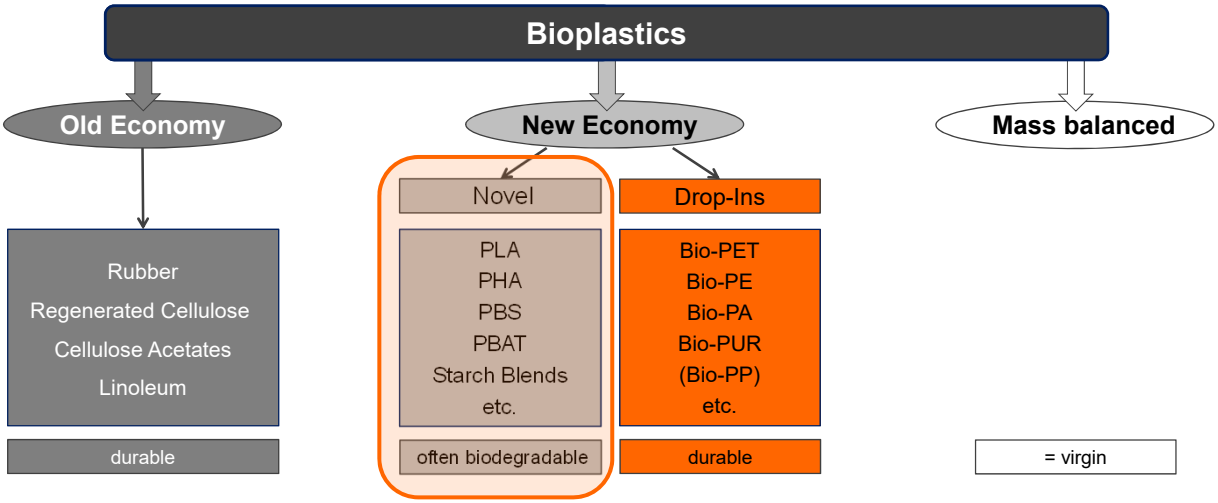
Approaches for the plastic industry to become CO_2-neutral







Old and New Economy Bioplastics



Source: H.-J. Endres, Adv. Biochem. Eng. Biotechnol, Springer, 2017, modified

Feedstock for biobased plastics

- **Direct use of renewable feedstock:**

Starch → Starch based polymers, Starch blends, Starch granules as filler
Cellulose → Cellulose derivates, Cellulose regenerates, Cellulose fibres for reinforcment
Vegetable oils → Polyamides, Biobased resins, etc.
Latex → Rubber
Etc.

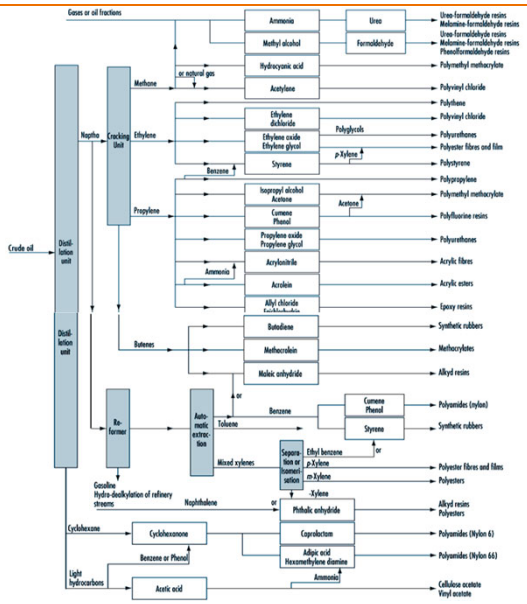
- **Fermentative use of renewable feedstock:**

Sugar or startch → Bioethanol → biobased „Drop Ins“: PE, PET, (PS, PVC, PP, etc.)
Sugar or starch → Polylactide PLA, Polyhydroxyalkanoates PHA, etc.
Fermentation of Cellulose
Biomethan → Bio-POM, etc.
(Other) biobased alcohols → biobased PUR, resins, elastomers, etc.
Etc.

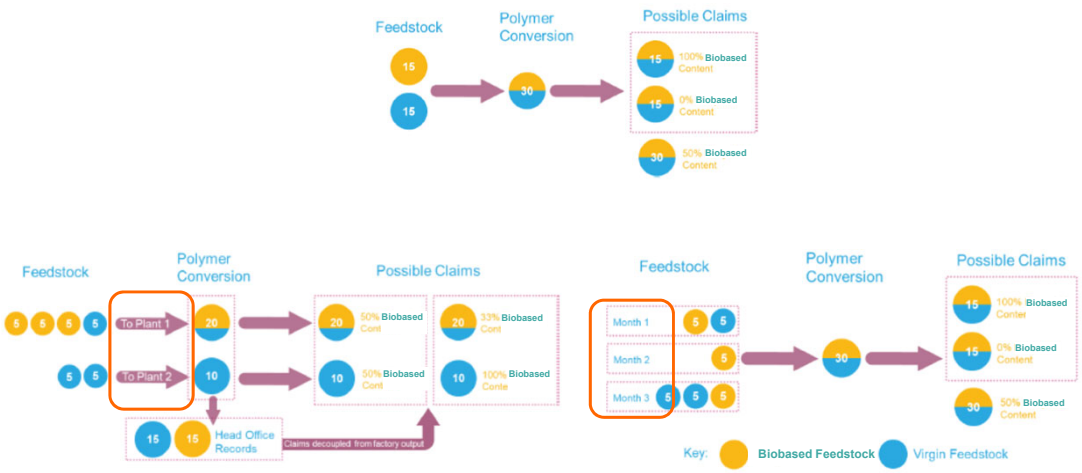
- **Mass balanced plastics**

New feedstock for chemical industry

- Naphtha cracker (mainly EU)
  - Feedstock: 100% crude oil (→ C3 – C6)
  - **Feedstock: Tall oil, UCO or HVO → Bionaphtha (C3 - C12/C16)**
- Gas cracker (USA)
  - Ethane, propane, +X mix,
  - Shale gas (ethane cracker)
  - **Biogas / Bio-methane**



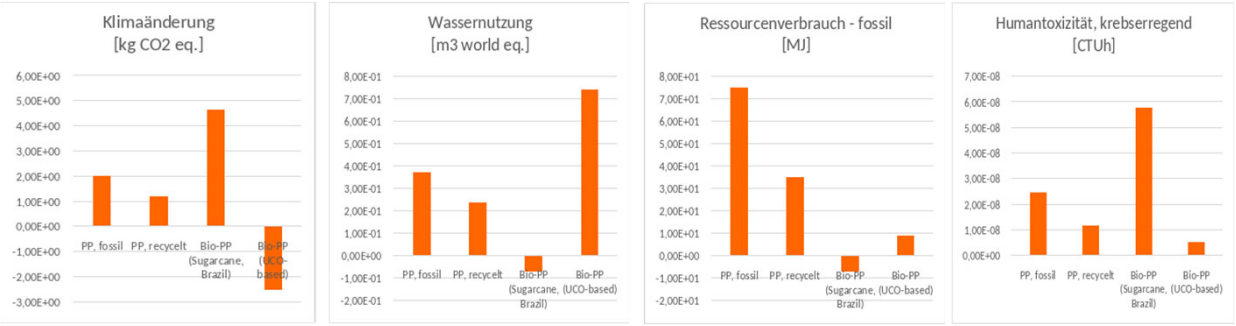
Mass Balance Approach



(Source: Eunomia Research Consulting Ltd., 2020, modified)

Ecological Impacts of PP, Bio-PP and r-PP (mechanically recycled) based on 1kg – Cradle to Gate

IKK Institut für Kunststoff- und Kreislauftechnik



Source: Compilation of Nessie et. al. (2020) and Moretti et al. (2020)

Summary

- **Recycling plastic is roughly about 50% better than producing virgin materials in <u>all</u> various categories**
- **Biobased plastics are partly better, partly worse than petorbased pendents in the various categories. It depends strongly on the process and the LCA parameters**