16. Processing and Utilisation I

- Recovered Paper, Recycling Glass, Scrap Plastic -

- "Paper" (from Greek/Latin: "Papyrus“ (pith of the papyrus plant) is nowadays defined as:
  - „Planar material made of fibres, predominantly of plant origin, which after exposing, suspension, and dewatering connect through chemical bonding via partial valency. This bonding reversible through addition of water.“
  - invented 105 AC in China, first produced from tree bark, rags, and fishing nets.
  - 1366 first mention of paper production in German (Nuremberg)
  - in the Middle Ages and up to the middle of the 19th Century, paper was also produced from rags , since 1825 also of mechanical pulp and cellulose.
  - towards the end of the 18th Century, invention of mechanical sheet formation in France; at the beginning of the 19th Century, mainly in England, development of the paper machine.
- “Recovered paper “
  - 1366 privilege of the council of the city of Venice granted to the (recovered) paper factory in Treviso to use the waste paper from Venice.

Paper Production in ancient times

Chinese Papermaker

Der Papyrer.

Ich brauch Hadern zu meiner Mül
Dran treibt mirs Rad deß wassers viel/
Daß mir die zschnitn Hadern nelt/
Das zeug wirt in wasser einquelt/
Drauß mach ich Pogn auff dē filtz bring/
Durch preß das wasser darauß zwing.
Denn henck ichs auff/laß drucken wern/
Schneweiß vnd glatt / so hat mans gern.

Abb. 12. Der Papyrer (aus dem Ständebuch von Amann)

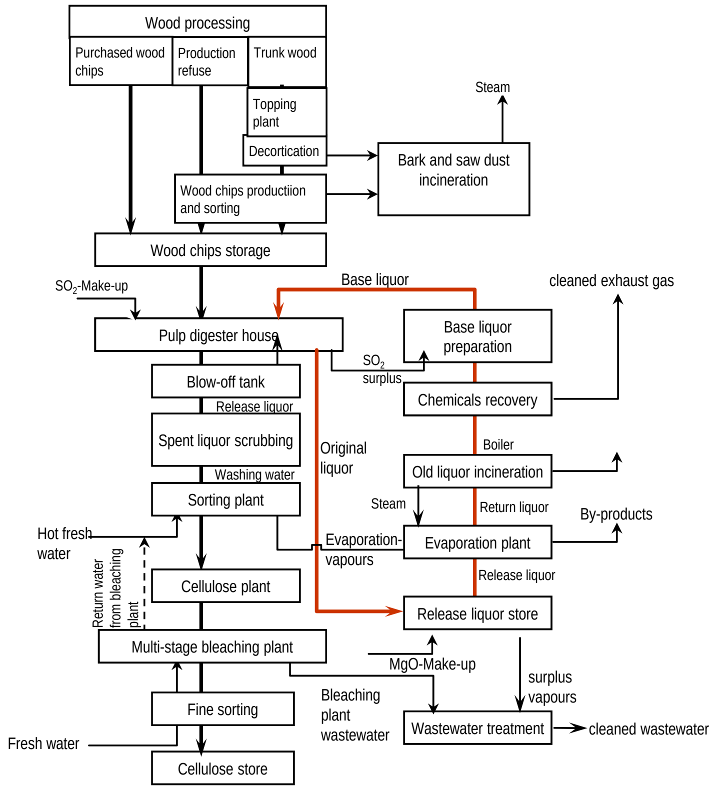
Cellulose

- **Cellulose** = part of wood remaining after chemical separation of the lignin (ca. 50% of the wood) as
  - **Sulphate pulp**, ($-SO_4^{2-}$) not produced in Germany, only imported; alkaline sulphate pulping with aqueous solution of soda lye, sodium sulphide and sometimes also soda being boiled for 4-6 hours at 170° to 190° C; sulphate pulp is difficult is bleach, thus so far only limited dispensing with chlorine bleaching possible; high tensile strength
  - **Sulphite pulp**, ($-SO_3^{2-}$) predominantly domestic production; acidic sulphite pulping with aqueous solution of magnesium or calcium sulphite; after evaporation of the base liquor, here also thermal utilisation and recovery of chemicals; cellulose of low tensile strength, but more easily bleachable (even without chlorine, with oxygen, H_2O_2 or O_3)
  - **Organosolv or ASM** methods; combination of acidic or alkaline disintegration with solvent processes (methanol);
  - **semi-chemical pulp** (cellulose with residual ratios of lignin)

(sulphides = salts of hydrosulphurous; sulphate = salts of sulphuric acid)

Production of Cellulose with the Magnesium-Bisulphite-Method

according to GÖTTSCHING, 1990

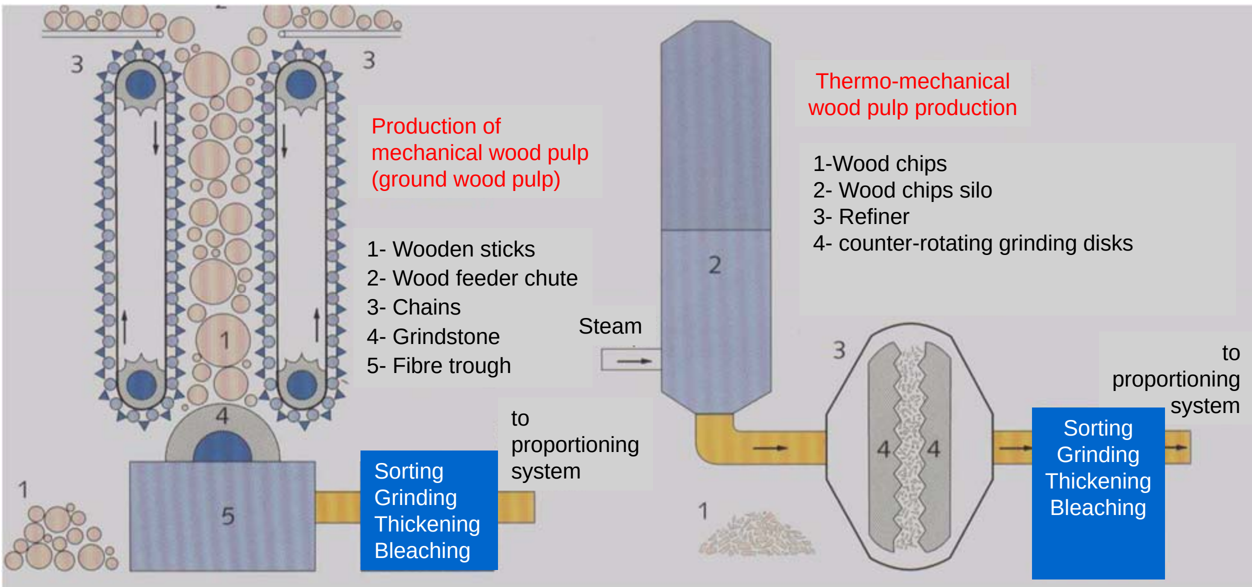


Further Paper Raw Materials / Products

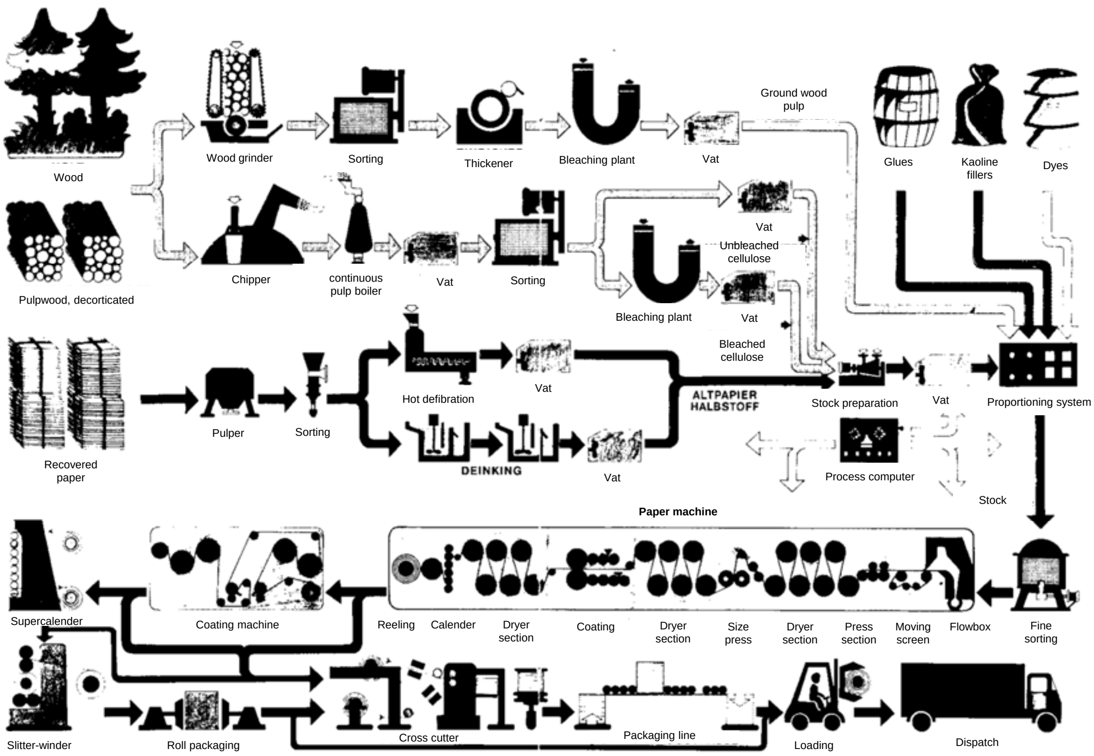
- Ground wood pulp for wood-containing paper (yellowing in the light), for instance for newspapers;
  - mechanical,
  - thermo-mechanical, and
  - chemo-thermo-mechanical production
- Recovered paper (RP) quantitatively the most important fibrous substance
- Auxiliary materials and filler: glue, white goods (lime, kaoline, etc.)
- Rags, for instance for banknote paper
- As for the products, one differentiates between (abbreviated as PCC):

Paper grammage according to DIN 6730	<	225 g/m²
Cardboard grammage according to DIN 6730	>	600 g/m²
Carton grammage according to DIN 6730	>	150 - 600 g/m²

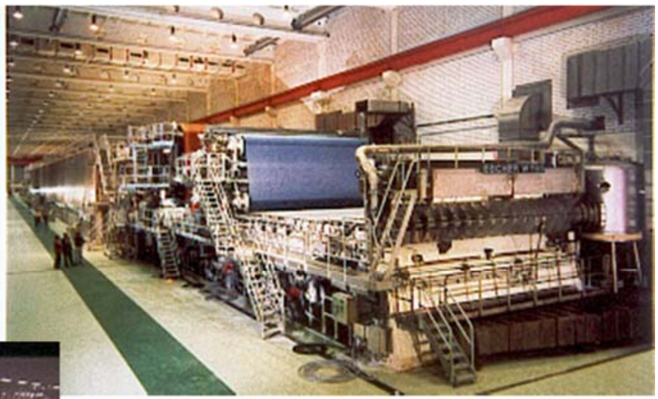
Production of Mechanical Wood Pulp



Paper Production

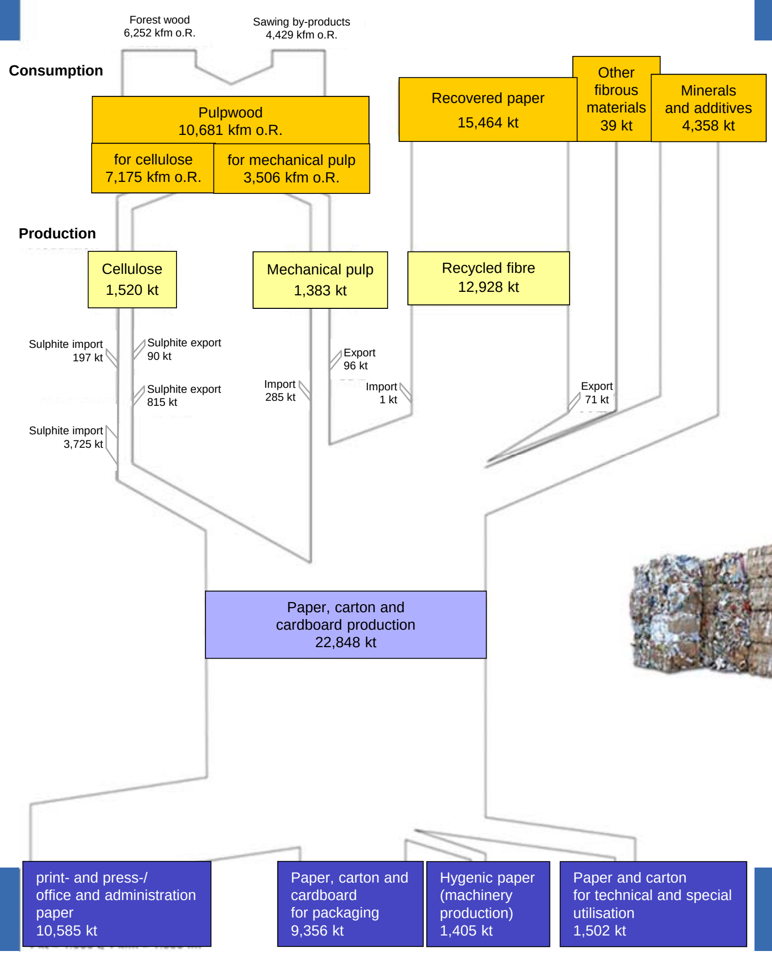


Papier Machines

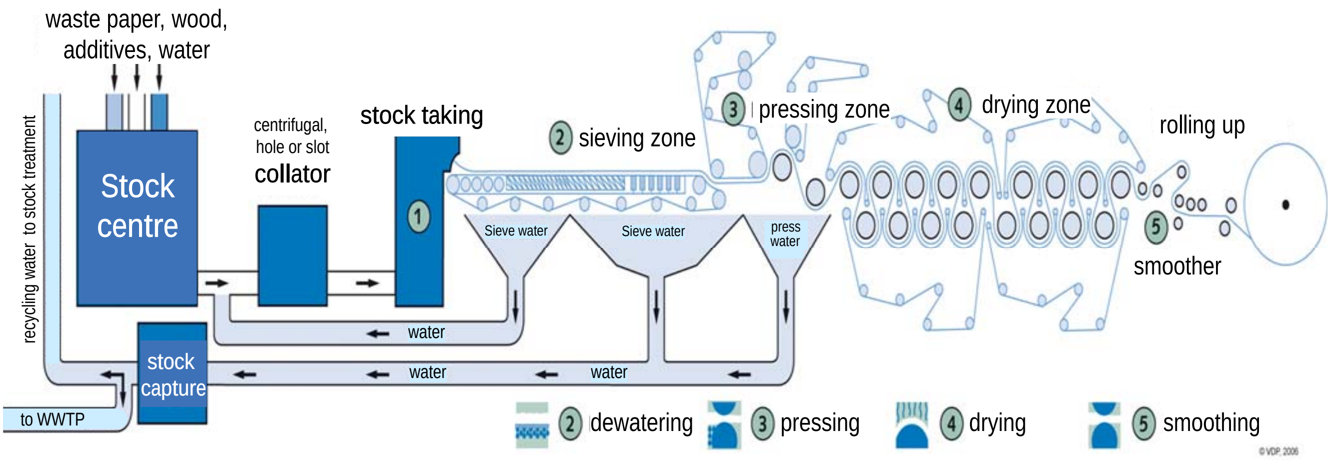


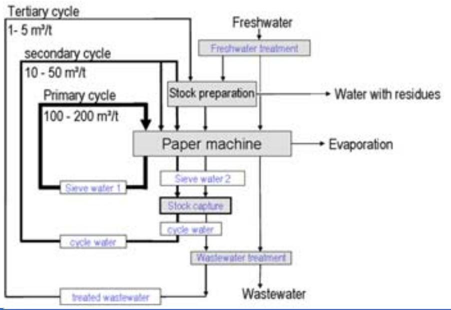
From raw materials to paper 2008

Paper Mass Flow in Germany (2008)



Wastewater Treatment in Papermillsd



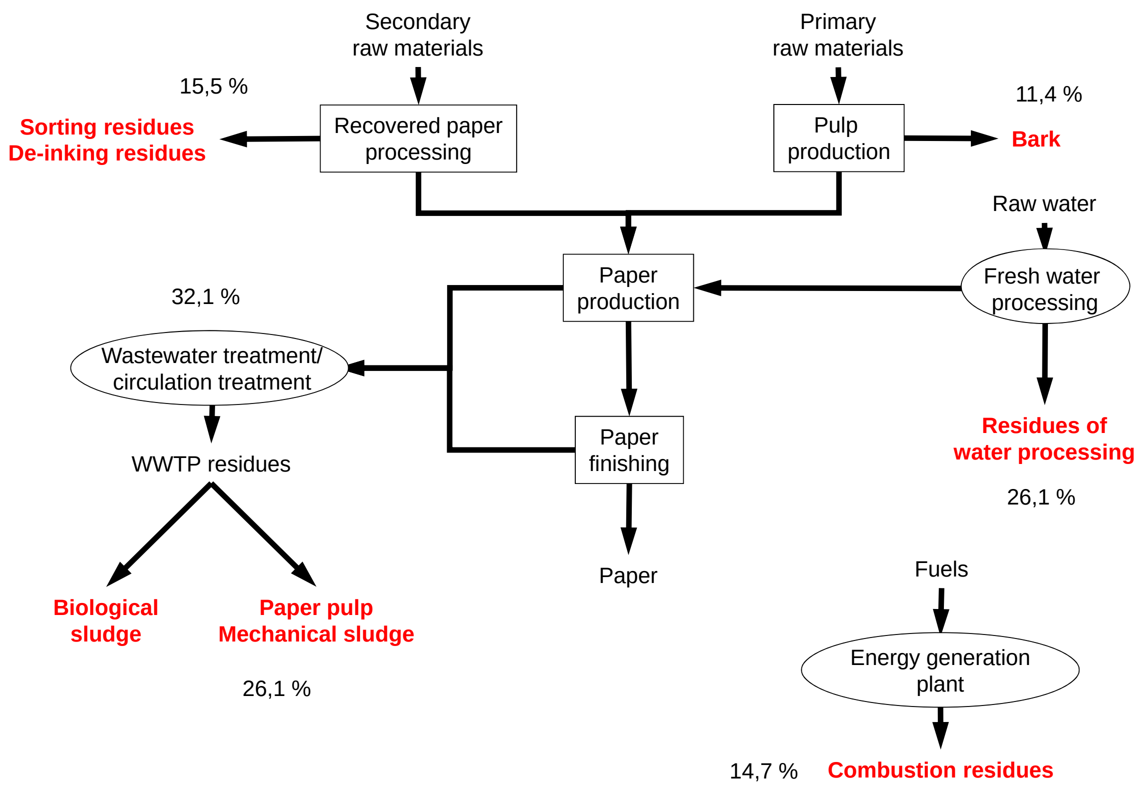


Recovered Paper Sources and Qualities

- Recovered paper (RP) is produced at various **points of origin**, for instance:
  - paper converting: large amounts per point of origin, sorted, unsoiled, higher qualities
  - unpacking business: medium to larger amounts, only packaging papers
  - households, administration, smaller shops: low amount per source, mixed lowest qualities
- **RP Types** (European List of Varieties (CEPI / B.I.R.))
  - Lower
  - Medium
  - Higher
  - Kraft paper
  - Special types

- **Extraneous material** (undesirable types of paper and material that is not paper)
  $\leq$ 3 or on average $\leq$ 2,5 weight %;
  at $\geq$ 10 weight % water $\rightarrow$ extractions

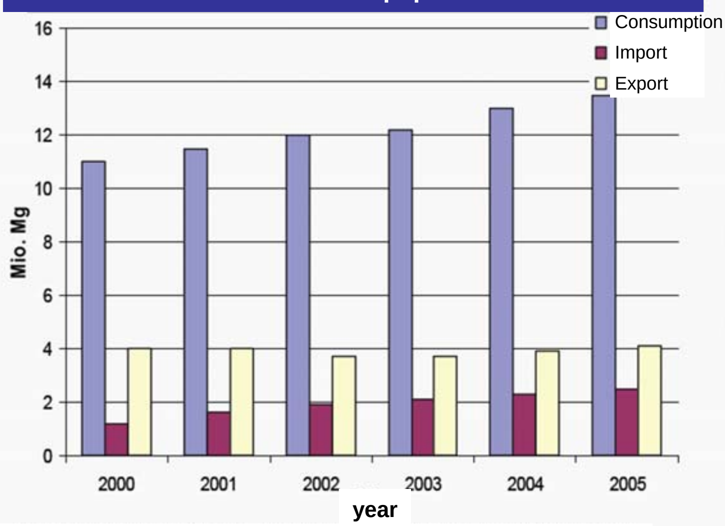
Typical Residues of Paper Production



Statistics of the German Paper Industry Association confirm the expected trend in regard to recovered paper

Market survey paper industry

Consumption, import and export of recovered paper



Source: Statistics of the German Paper Industry Association, FEA

Outline data on recovered paper collection

- In 2002 to 2005, the annual average of recovered paper that was collected amounted to ca. 13.9 Mg
- Broken down to single sources:
  -ca. 1.4 m tons industrial
  - ca. 6.2 m tons commercial
  -ca. 6.3 m tons domestic
- Average per capita domestic production **ca. 76 kg** per year = 15,833 DIN A4 sheets
- Average per capita domestic and commercial production **150 kg per year**

➢ **90% of the entire recovered paper are collected by private and municipal disposal contractors!**

Solid Waste Management
Dr.-Ing. Dirk Weichgrebe
Leibniz Universität Hannover

Development of the Prices for Mixed Recovered Paper

Statistisches Bundesamt

Germany

Index of the wholesale prices for recovered paper

2005 = 100

Reporting year	Jan	Feb	Mrz	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Annual average
	Mixed recovered paper (B 12 - .02), weight 100% Interlinking factor 1.70553												
1999 ...	.	.	.	.	.	.	64,1	87,2	83,2	75,7	78,6	76,2	.
2000 ...	79,3	103,4	145,0	219,0	237,8	242,4	240,8	208,8	172,8	153,0	141,9	102,8	170,6
2001 ...	66,2	61,7	63,3	64,8	64,3	60,9	61,7	64,1	67,5	69,6	70,8	70,4	65,4
2002 ...	70,1	68,9	70,1	91,2	132,2	239,6	237,2	190,3	128,8	104,7	105,4	105,9	128,7
2003 ...	106,8	108,6	130,3	177,4	133,9	97,6	98,6	98,6	119,4	128,1	93,6	82,4	114,6
2004 ...	84,3	110,2	117,5	119,9	118,0	106,3	107,3	107,4	107,8	121,3	114,8	96,4	109,3
2005 ...	86,3	97,8	116,6	118,9	114,8	98,9	92,3	93,8	94,3	96,6	96,5	92,9	100,0
2006 ...	91,0	90,1	90,6	113,1	114,6	115,6	115,8	115,7	115,7	116,4	117,1	117,3	109,4
2007 ...	118,9	132,8	152,5	154,6	155,5	160,2	177,5	182,2	186,4	188,5	175,1	155,8	161,7
2008 ...	155,6	174,6	175,2	164,9	144,8								
2009 ...													

The index is calculated thus:

$$I = \frac{\sum_{i=1}^{n} \frac{p_{ti}}{p_{0i}}}{n}$$

With:

- pti — price of company i in the reporting month t (= reporting price
- p0i — price of company i in the basic year 0 (= basic price)
- n — number of reports

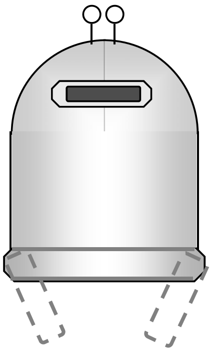
RP Collection

- RP **cannot be recycled any number of times** (fibre shortening);
  → paper leaves the loop via sanitary paper or energetic utilisation

- **Collection costs** depend, for instance, on the bulk density

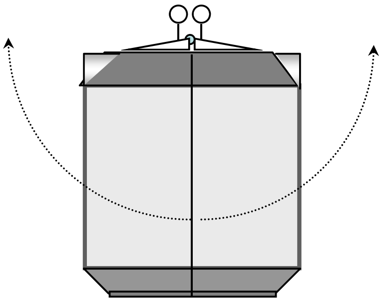
▪ print products		approx. 250 kg/m³
▪ mixed domestic RP	in MWC	80 - 160 kg/m³
	in large containers	100 - 200 kg/m³
▪ cardboard/carton		40 – 60 kg/m³

Recycling glass and Recovered paper - Container



Recovered paper

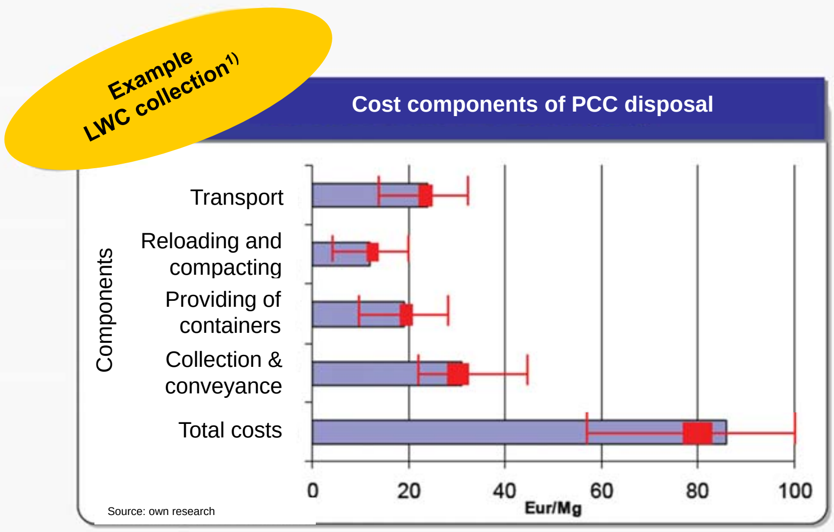
Container GFK



Recovered paper

Container Stahl

Overall costs in relation to the realised collection system
There are massive variations on the market



1) Mixed collection, subcontraction

Cost drivers:
- Collection system
- collection rhythm
- worthwhile collection
- provided volume
- Transport distances
- etc.

➢ **Eventually, the PCC collection can today be designed in such a way that the utilisation profits cover the collection costs**

Solid Waste Management
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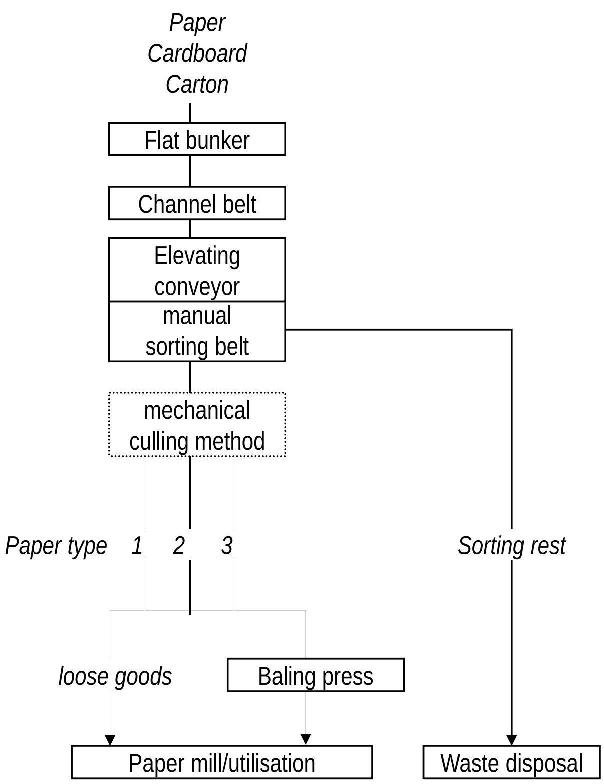
Collection of Domestic RP according to Bilitewski, 2003

- **RP collection**
  - ca. 50 % commercial through private disposal contractors (BVSE or BDE)
  - ca. 50 % domestic (lower qualities) through public disposal contractors/DSG: packaging and print products RP 25% / 75% Fee regulation):
    - Bundle system / loose — 40 - 60 kg /P·a
    - RP Depot Container — 40 - 60 kg /P·a
    - RP Mono-Container (collection) — 50 - 90 kg /P·a

	1992		1994		1997		2000	
	m Mg/a	%	m Mg/a	%	m Mg/a	%	m Mg/a	%
Depot container	1,51	39,0	2,47	49,3	2,814	49,2	2,610	48,5
Bundle collection	0,55	14,2	0,35	7,0	0,395	6,9	0,285	4,6
RP Mono-Container	1,71	1,71	1,75	34,9	2,025	35,4	2,958	47,1
Other systems	0,01	2,6	0,44	8,8	0,485	8,5	0,432	6,8
Sum	3,87	100	5,01	100	5,719	100	6,285	100
Packaging paper	1,36	35,1	1,40	27,9	1,086	19,0	1,404	22,3
Graphic paper	2,51	64,9	3,61	72,1	4,633	81,0	4,881	77,7
Sum	3,87	100	5,01	100	5,719	100	6,285	100

RP Sorting



- Prior to fine processing at the paper mill, sorting according to
  - components which are alien to paper
  - undesirable types of paper
  - Positive sorting of de-inking goods
- Manual sorting performance:
  - 500 - 1500 kg/sorter · h Negative sorting of brown imbued PCC
  - 250 - 400 kg/sorter · h Positive sorting of de-inking goods or magazines

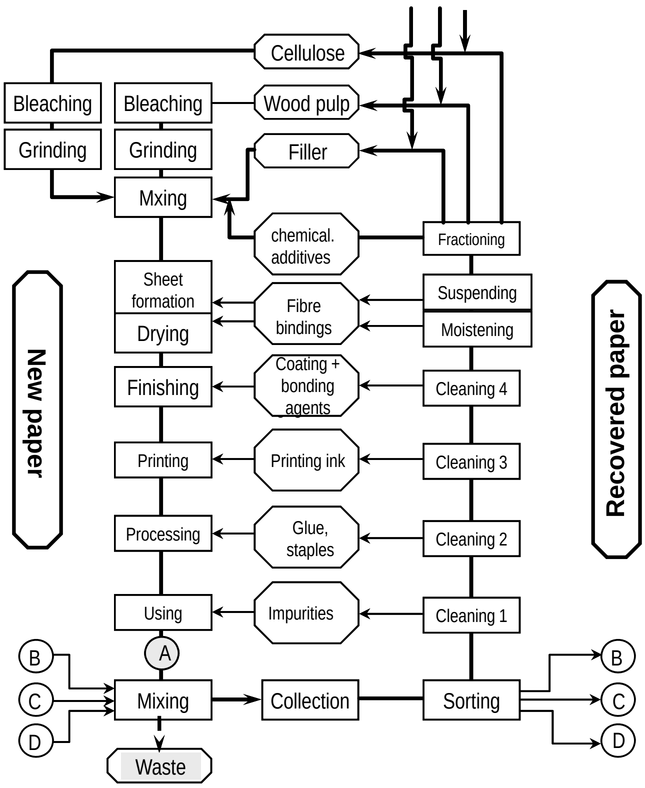
RP Pollutant Contents

		Separatel collected mixed recovered paper	Sorting fraction Paper/Cardboard from domestic waste (GREINER, 1983)	Compost Category 1 according to Bio-Waste Ordinance 98
Water contents	Weight %	6 - 8	24,0	
Caloric value Ho	kJ/kg DS	15.000 - 18.000	16,3	
Caloric valueHu,raw	kJ/kg	14.000 - 16.000	10.950	
Ignition loss	Weight %	85 - 90	86,8	
Carbon	Weight %	41	40	
Iron	mg/kg DS	1000 -2000	2000	
Lead	mg/kg DS	10 - 50	125	100
Cadmium	mg/kg DS	0,1 - 1	1,6	1
Chromium	mg/kg DS	3 - 40		70
Copper	mg/kg DS	20 - 30	100	70
Mercury	mg/kg DS	<0,1	0,15	0,7
Zinc	mg/kg DS	50 - 300	375	300
Fluoride	mg/kg DS	-	31	
Chlorine	mg/kg DS	1300	2925	
Sulphurousl	mg/kg DS	-	900	
PCB	mg/kg DS	0,01 - 6		
PCDD	ng TE/kgDS	0,17 - 12		

- no RP from waste
- in the waste, RP is a fraction with low heavy metal contents;
  lead in printing dyes = in the past before 1985
- organic pollutants possible from chlorine bleaching, pigments, paper finishing

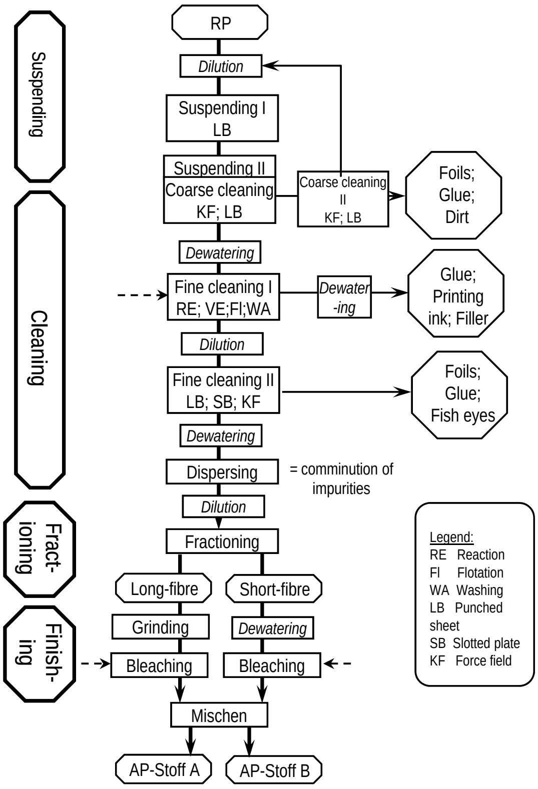
RP Processing as Reversal of Production and Product Usage

according to BAUMGARTEN, 1987



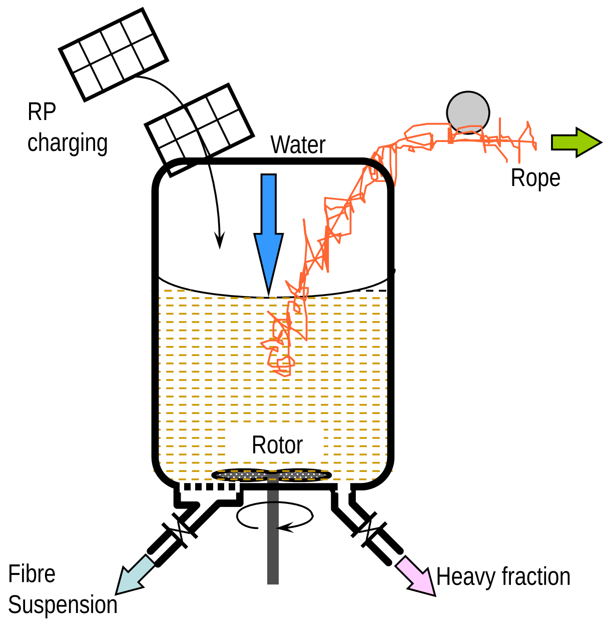
Process Stages of Recovered Paper Processing

according toh BAUMGARTEN, 1987

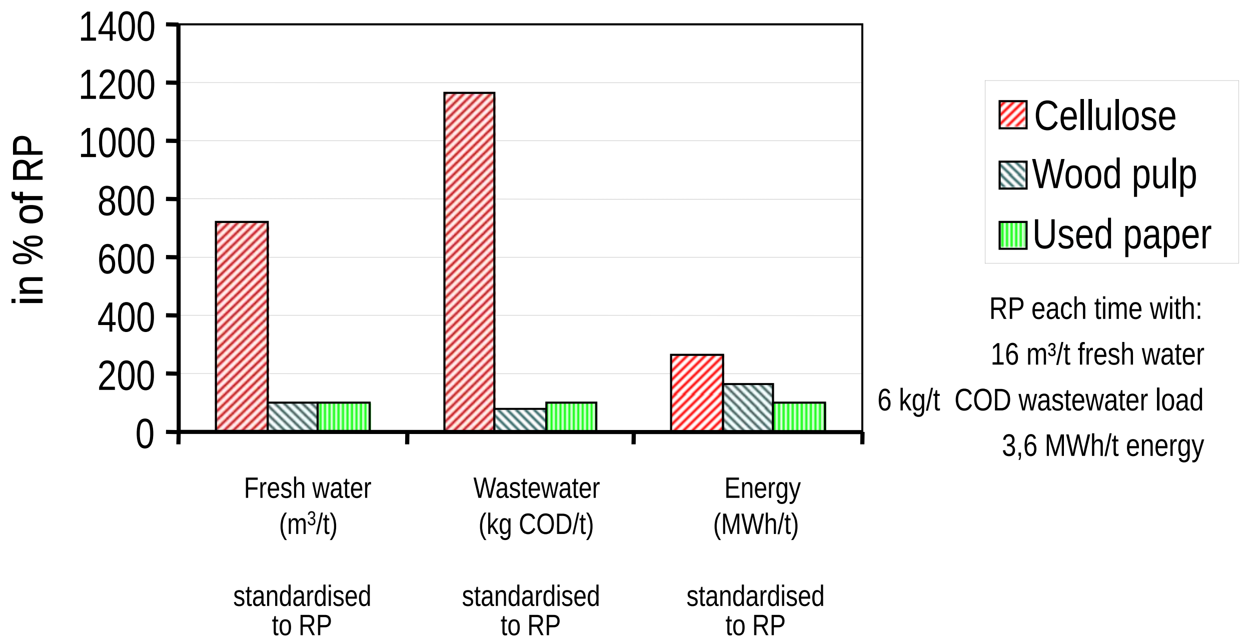


- De-inkability limited → pre-sorting
- Sticky impurities
- there are special processing plants for for beverage composite cartons from DSG-LWPs (Fibre; PE, Al)

Pulper



Eco-Balance of Paper Production with/without RP



RP each time with:
16 m³/t fresh water
6 kg/t COD wastewater load
3,6 MWh/t energy

Source: BVP using FEA data

RP Utilisation outside the Paper Industry

UTILISATION	PROCESS	APPLICATION PURPOSE
Using the fibre properties	Dry processing Wet processing	Chipboards, palettes, moulded articles, **heat insulation material**, litter for livestock farming **Fibre boards** (e.g. Rigips, Fermacell); flower pots, planting tubs
Using the chemical properties	Hydrolysis, fermentation Pyrolysis	Glucose, alcohol, protein Gas, oil, coke
Energetic utilisation	Incineration (pyrolysis) Tile production	**Steam, electric energy** (energetic utilisation) Porous tiles (expanding agents)
Biological utilisaiton	Composting	Compost

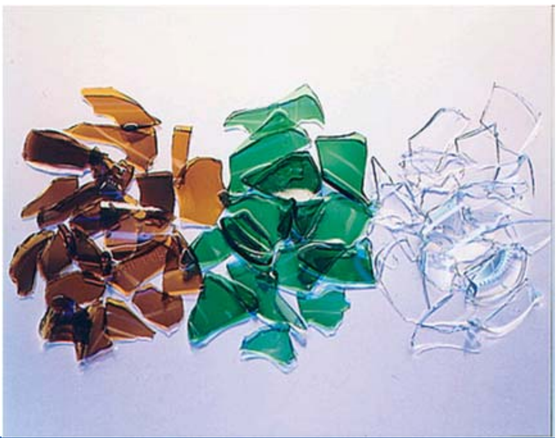
Recovered Glass

Behaviour of Disposed Waste Glass

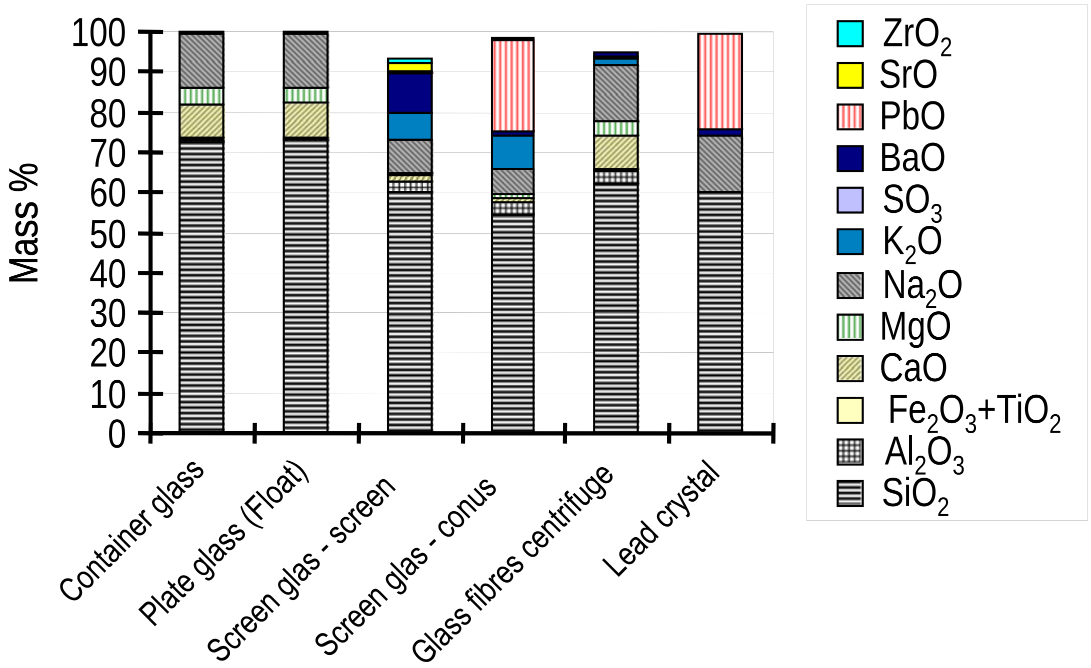
- Inert, not elutable
- The weight cannot be reduced through treatment (GIP or MBT)
- If disposed: high landfill area demand; no emissions, however

- Material utilisation ideal, as there is as good as no quality loss in the recycled material and as the melting of RG makes for energy saving compared to the raw material

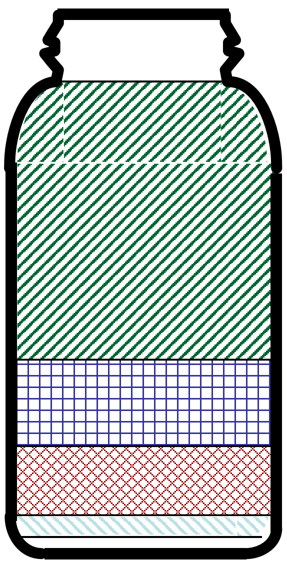
- Different recipes for different glass products; different glass colours for container glass



Composition of Glass



Raw Material Ratios in Container Glass



ca. 60% quartz sand SiO_2

ca. 18% Soda Na_2CO_3

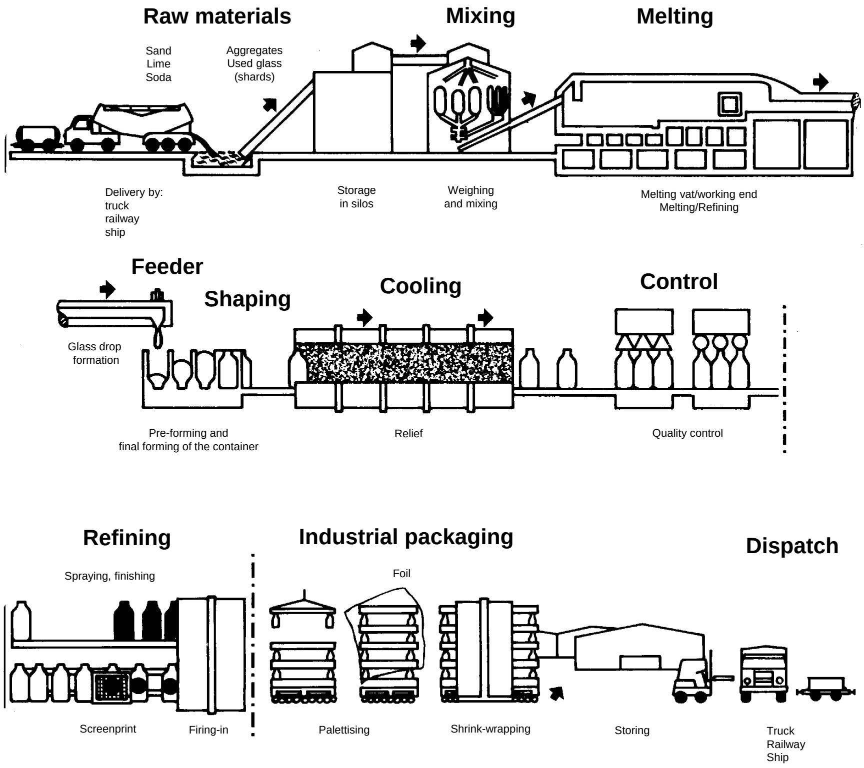
ca. 15% limestone $CaCO_3$

ca. 6% feldspar

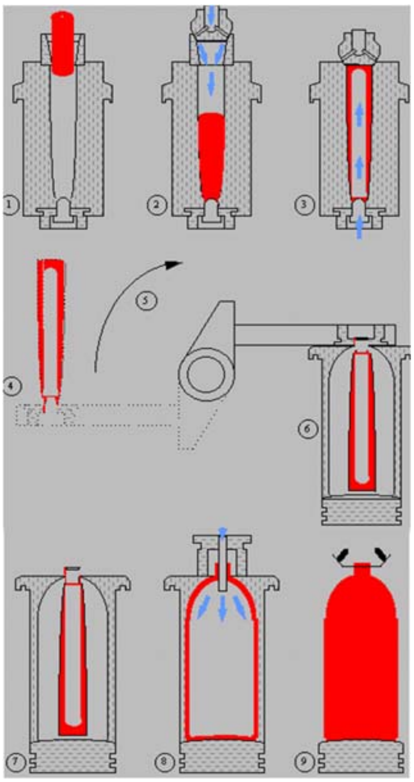
after elusion of the CO_2
Na_2O and CaO

ca. 1% refining agents, discolouring agent (selenium),
Dyes: chromic oxide for green glass, coal dust for brown glass

Container Glass Production

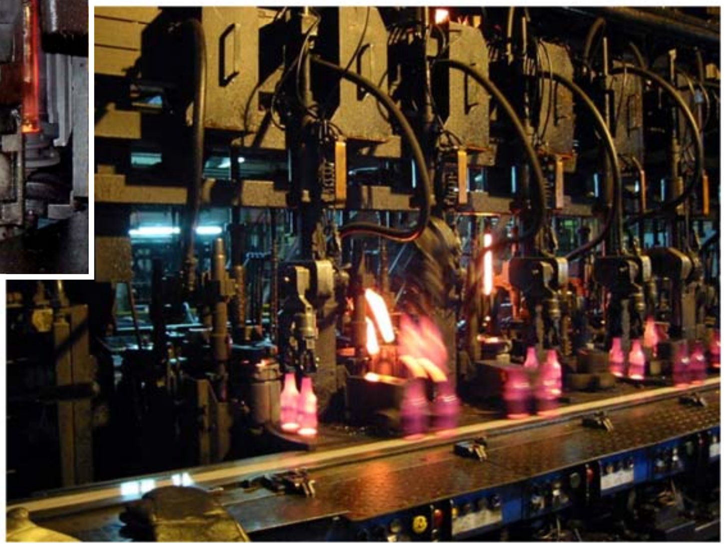


Moulding of Container Glass



- top:
  Blowing of the pre-form/of the parison from glass drops
- Moving of the parison into the finished forging
- Blowing of the finished forging

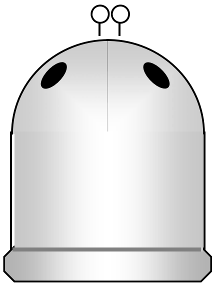
Glass Machine



RG collection

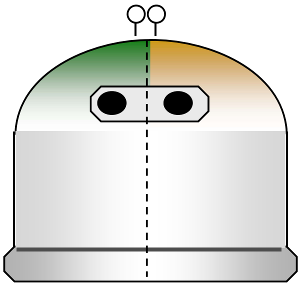
- **Potential** for container glass: 35 - 50 kg/P·a
- **Bulk density**
  - unbroken in RG container 250 - 300 kg/m³
  - RG shards broken in a baffle mill ca. 1.500 kg/m³
- **RG collection**
  - RG container (delivery system), separate setting up according to colours white/brown/green; 25 - 45 kg/P·a
  - RG mono-container (collection system, for instance with restaurants); LWC 120/240/660/1100; canteens, homes, and in multi-family housing areas 25 - 45 kg/P·a
  - RG Yellow Bag (collection system); 40 to 50 L PE bags; 10 - 25 kg/P·a in areas with residual waste bag removal; combination with container collection recommended
- **Revolving emptying container,** delivery system as 1-5 m³ GRP or steel plate container, if possible sound-proofed; emptying by hook crane with drop bottom outlet into open trucks with colour-separated superstructure with up to 50 m³ volume.
- Container with integrated colour separation were tested, but could not prevail.
- Material utilisation also for **plate glass**:
  - Production > 2.000.000 t/a
    Plate glass waste ca. 500.000 t/a; of which utilised ca. 300.000 t/a

Recycling glass – Container and Truck Loading Process



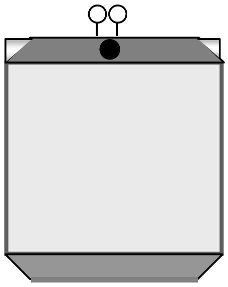
Recycling glass

Container GFK



Recycling glass

Container GFK
mit 2 Kammern



Recycling glass

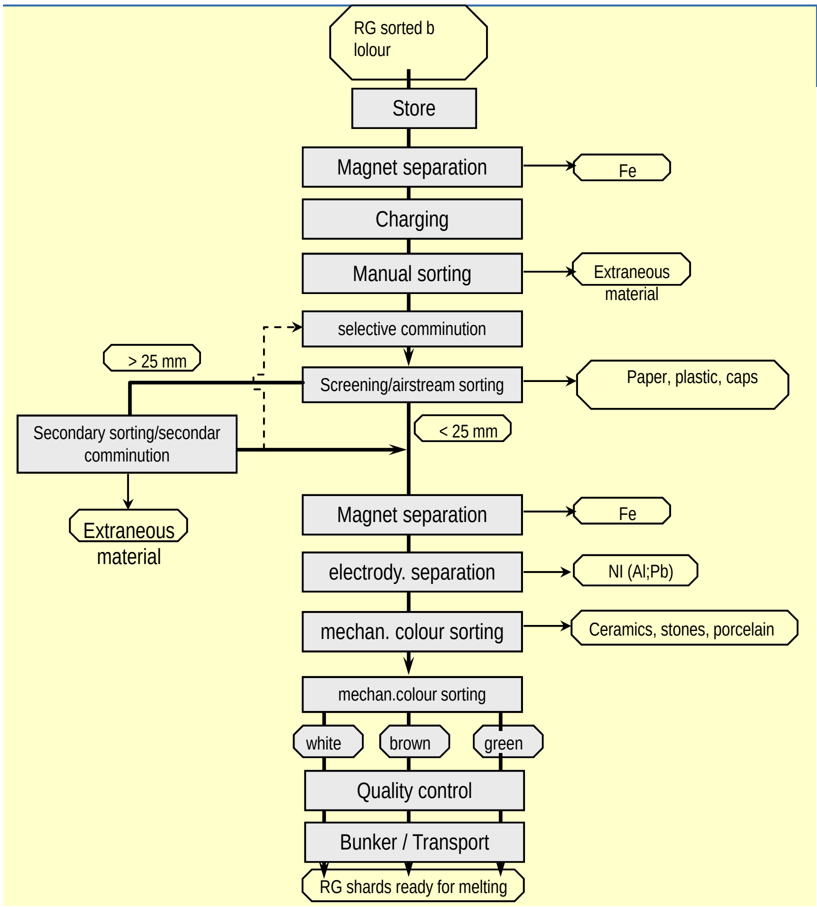
Container Stahl

Foreign Material in RG / Quality Requirements

- Foreign material in the RG which must be separated:
  - **organic substances**, i.e. paper and plastic, which locally disturb the redox balance
  - **iron, lead, and tin** destroy fire-proof vat bottoms
  - **aluminium** remains in the glass vat, reduces SiO_2 and causes silicium inclusions in the glass, which in turn reduces the pressure resistance)
  - **porcelain, ceramics, and stones** → inclusions in the glass

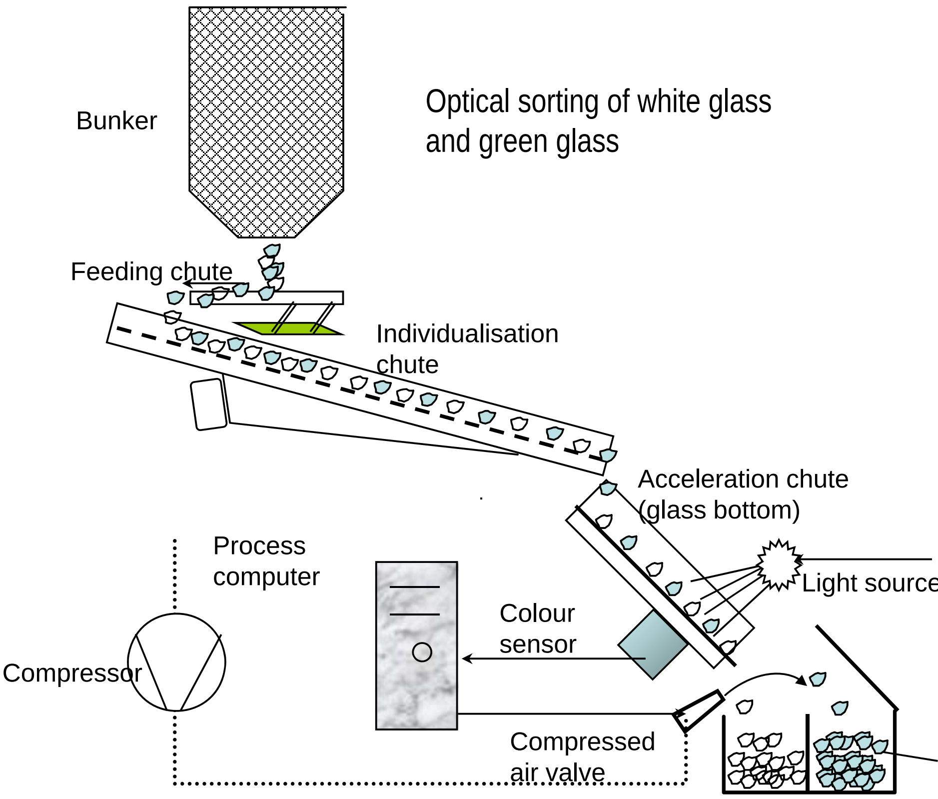
Parameter		Requirements	
		not conditioned	conditioned
Purity in weight %	According to specifications Sum of excluded foreign material; Sum of excluded glass qualities Off-colour ratio (in white), of which ≤ 1,00 % green and ≤ 2,00 % brown Off-colour ratio (in brown) Off-colour ratio (in green)	≥ 97% ≤ 1,00 % ≤ 2.00 % ≤ 3.00 % ≤ 8.00 % ≤ 15.00 %	≤ 0.2 % ≤ 5 % ≤ 10 %
Excluded glass qualities	Quartz glass (e.g. laboratory appliances), fireproof glass (e.g. crockery), glass ceramic (e.g. cooking plates)	≤ 0.15 %	
	Glass from electronic appliances (e.g. screen glass)	≤ 0.20 %	
	Lead crystal Wire glass Car glass (particularly laminated glass) Plate glass	≤ 1.00 % ≤ 0.20 % ≤ 0.20 % ≤ 2.00 %	
Excluded foreign material	Clay jugs and bottles, other ceramics, stones, slags, earth Metals (including bottle caps, sleeves, lead capsules) other waste (incl. other packaging materials)	≤ 0.15 % ≤ 0.35 % ≤ 0.50 %	≤ 25 g/t ≤ 1-5 g/t
hyg. harmful waste	Principally lead to refusal of acceptance		
Manner of delivery	If possible, from direct deliver without compacting		

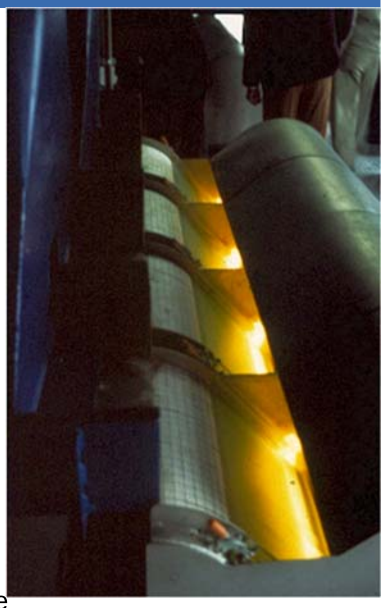
RG Processing Plant



Optical Sorting of White Glass and Green Glass

Optical sorting of white glass and green glass





RG Utilisation outside of the Container Glass Industry

- Only a small ratio of the RG is utilised outside the glass production industry (due to cheaper competitor products):
  - **Glass wool,** used, but competition to rock-wool mineral fibre
  - **Foam glass** high-grade insulation material
  - **Glasphalt** aggregate in blacktop for road construction; competition to high-quality split and crushed sand
  - **Glass reflector pearls** aggregate to reflective paints
  - **Glass powder, glass sand** abrasive material

- **Plate glass shards** to plate glass

- **Television tube glass** unsuitable as container glass due to the high lead oxide contents (< 100 ppm lead according to § 13 Packaging Ordinance).

Scrap Plastic

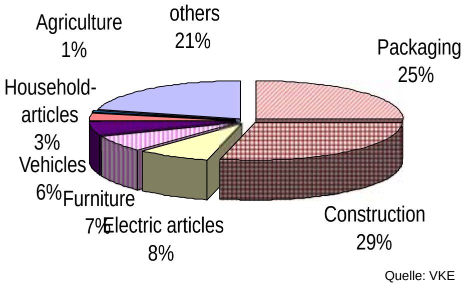
Types of Plastic

- **Thermoplastics**: linear or branched polymers (chains of monomers), whose polymer chains are not cross-linked and which can be plastically softened reversibly by heating up to flowability. Recycling is possible through melting.
- **Duroplastics**: synthetic plastics, hardened from the reaction of several pre-products which are capable of flowing. The hardness changes only little before the category temperature of polymer degradation is reached.
- **Elastomers**: non-meltable, permanently elastic plastics (e.g. SBR).

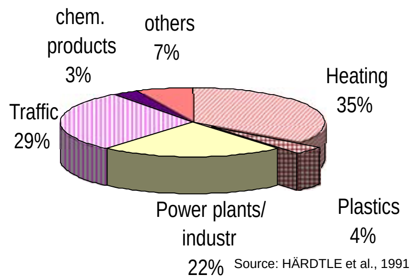
Plastic	Short form	Application Areas
Thermoplastics		
Polyethylene	PE (HD/LD)	Foils, moulded parts, mass produced articles; construction elements, e.g. pipes
Polyethylenterephthalate	PET(P)	Beverage bottles, wear-resistant elements for precision mechanics, housings for appliances, foils
Polybutylenterephtalate	PBTP	Friction bearings, castors, housings for spark plugs
Polypropylene	PP	Technical parts, e.g. in cars; pipes
Polyvinylchloride	PVC	Foils, window frames, pipes, cable insulation; 57 weight % chlorine
Polystyrene	PS	Disposable cups, household articles, injection moulded parts, styrofoam
Polyamide	PA	Cogs, fibrous materials, wall dowels, housings for electric appliances
Polymethylmethacrylate	PMMA	Tail lights, sanitary articles, watch-glasses
Polycarbonate	PC	CDs, round rods, bottles, ampullae
Duroplastics		
Polyester	UP	Casting resin, lacquers, fillers
Epoxy resin	EP	Lacquers, casting resin, glues
Phenolic resin	PF	Electric insulation materials, hardboards, casting and paint resins, wood glue, chassis parts (Trabant)
Melamine resin	MF	Binding agents for moulding materials, wood glue, lacquers
Urea resin	UF	Binding agents for moulding materials, wood glue, lacquers
Polyurethane	PUR	Casting compounds, coating colours, foams, lacquers
Elastomers		
Natural caoutchouc	NR	Soft and hard rubber, hoses, sealings
Styrol-butadien-caoutchouc	SBR	Car tyres
Polybutadiene	BR	Car tyres, lining material, insulation material
Polychlorpropene	CR	Conveyor belts, cable cleading, foam rubber, protective clothing

Application of Plastics

Application example	Plastics used	Application example	Plastics used
Crockery, cutlery, kitchen articles, housings	PE, PP, PVC, PA, PS, PC, EPS	Beverage bottles for CO_2 containing drinks	PET
Tablecloths, coverings	PVC soft	Diffusion-tight composite foils for foodstuff	PE (Al-kaschiert), PET, PVDC
Bathroom furnishing	PVC	Shrink-wrap bags for packaging	PE, PVC (weich)
Carrier bags	PE, (PVC)	Boil-in-bag package	PE
Hollow bodies (large containers, bottles, canisters)	PE, PP, PVC	Tubular bags for liquids	PVC, PE
Packaging foils	PE	Packaging cans, cups, fruit baskets, cutlery trays	PE, PP, PVC



Application areas of plastics



Mineral oil consumption

ISAH
Solid Waste Management
Dr.-Ing. Dirk Weichgrebe
Leibniz Universität Hannover

Plastic waste in Germany in 2003

Types of waste	Amount in kt	Post-consumer in kt	Producers + fabricators in kt
PE-LD/LLD	947	822	125
PE-HD/MD	469	392	77
PP	425	272	153
PS/EPS	309	136	61
PVC	492	356	148
Styrol Copolymere	75	48	27
PMMA	31	20	11
PA	72	37	35
PET	193	162	31
Other thermoplastics	96	56	40
Durolastics (incl. PUR)	458	278	180
non classifiable	438	438	0
Total	**4005**	**3117**	**888**

Utilization of Plastics

In Germany, one of the biggest producers of plastics worldwide, about 16.8 m tons of plastics were produced in 2003, ca. 10.6 m tons were consumed. More than 60% of all processed plastics are thermoplastics, such as

- Polyethylene PE (2.74 m t),
- Polyvinylchloride PVC (1.52 m t),
- Polypropylene PP (1.71 m t)
- Polystyrene PS (0.60 m t)
- Polyethylenterephthalate (0.41 m t).

About 10% of the total processed amount are thermoplastic construction plastics, such as polyamide PA, polycarbonate PC, or acrylnitrilbutadienstyrene ABS, ca. 30% are duroplastics.

In 2003, a total of about 4.0 m tons of plastic waste were produced in Germany, of which
2.34 m t (58.4 %) were **utilised**
(33.7 % material utilisation, 10.0 % resources utilisation, and 14.7% energetic utilisation), and

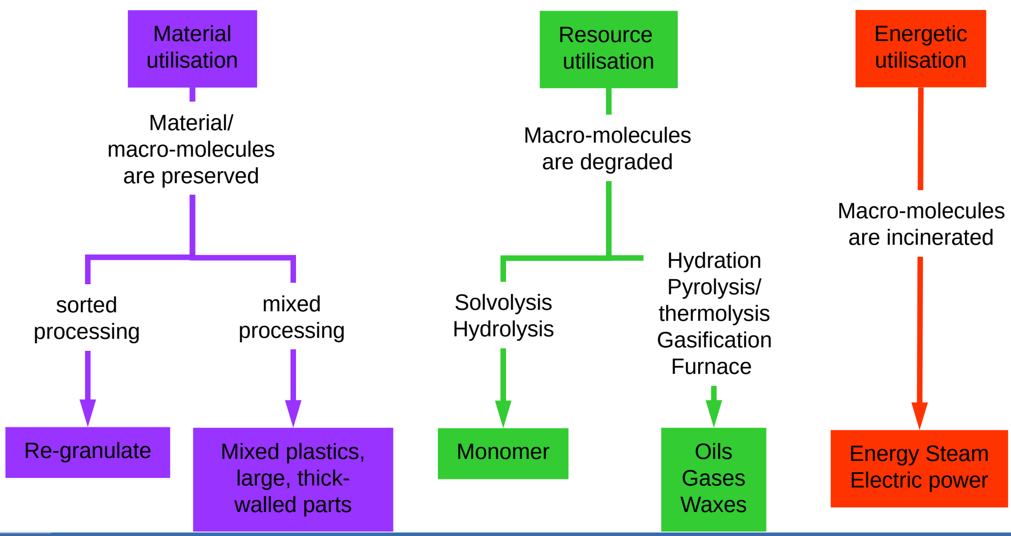
1.67 m t (41.6 %) were **disposed**
(22.0 % depositing and 19.6 % incineration without waste heat usage).

Chemical Components and Caloric Value of Plastics

Type of Plastic	Ratio in weight %						Caloric value
	C	H	O	N	Cl	F	kJ/kg
PE	85,7	14,3	-	-	-	-	46.000
PP	85,7	14,3	-	-	-	-	46.000
PS	92,3	7,7	-	-	-	-	40.500
PUR	62,1	3,4	18,4	16,1	-	-	24.000
PA	63,7	9,7	14,2	12,4	-	-	33.400
PVC	38,4	4,8	-	-	56,8	-	18.000
PTFE	24		-	-	-	76	8.400
Mixed plastics in domestic waste							18.300 (H_u) 26.200 (Ho)

- Plastics also contain:
  - **Softeners** (organic compounds, e.g. in PVC soft),
  - **Stabilisators** (heavy metal-containing with Pb, Cd (mainly in construction parts made of PVC hard), Zn and Sn),
  - **Light stabilisers and flame retardants** (frequently brominated organic compounds)
  - **Colour pigments** (mostly heavy metal-containing (Cd (strongly decreasing)), Cr, Cu, Ni, Pb, Zn), and
  - **heavy metal catalysts** (titanium in PE-HD and PP, chromium in PE-HD).

Production and Utilisation Amounts of Plastic Waste in the Different Waste Production Areas			
Point of origin	Waste amount in kt	Utilisation amount in kt	Utilisation rate in %
Plastic production	86	81	94
Plastic processing	802	710	89
commercial final consumption	1.402	714	51
private final consumption	1.715	833	49
Total	4.005	2.338	58,4



Plastics used in Waste Incineration

- On average, municipal waste contains 1% PVC;
- **Cl ratio in PVC** and chlorides are converted in the garbage incineration plant → **HCl**
  - With **neutralisation** with crystallisation of the salt, $CaCl_2$ or NaCl are released – at stoichiometric conversion, in the following ratios per t of PVC:
  - (23+35)/35 · 0,57 = 0,94 t NaCl or (40+235)/35 · 0,57 = 0,90 t $CaCl_2$.
  - Due to leaner-than-stoichiometric dosage, there result >1t salt/1t PVC (disposal as special waste)
  - Or **utilisation** as NaCl in chlor-alkali electrolysis or HCl dilute acid in the industry
- The analysis results (e.g. MARTIN/ZAHLTEN, 1989 and KARASEK et al., 1983) about the **production of PCDD/ PCDF** or Chlorobenzene emissions through increased PVC contents partly contradict each other. Experiments at the GIP Würzburg (KERBER, 1994) with additions of 7.5 and 15 weight % of plastic residues (and thus PVC contents increased accordingly) showed no deterioration of the raw and clean gas emissions. Obviously, for the "de-novo synthesis" of PCDD/PCDF the chlorides in the remaining waste are sufficient.
- Heavy metals from plastics are an important pollutant ratio in the raw gas emissions, for instance in dusts and flue gas treatment.

Plastics in Depositing and Biological Treatment

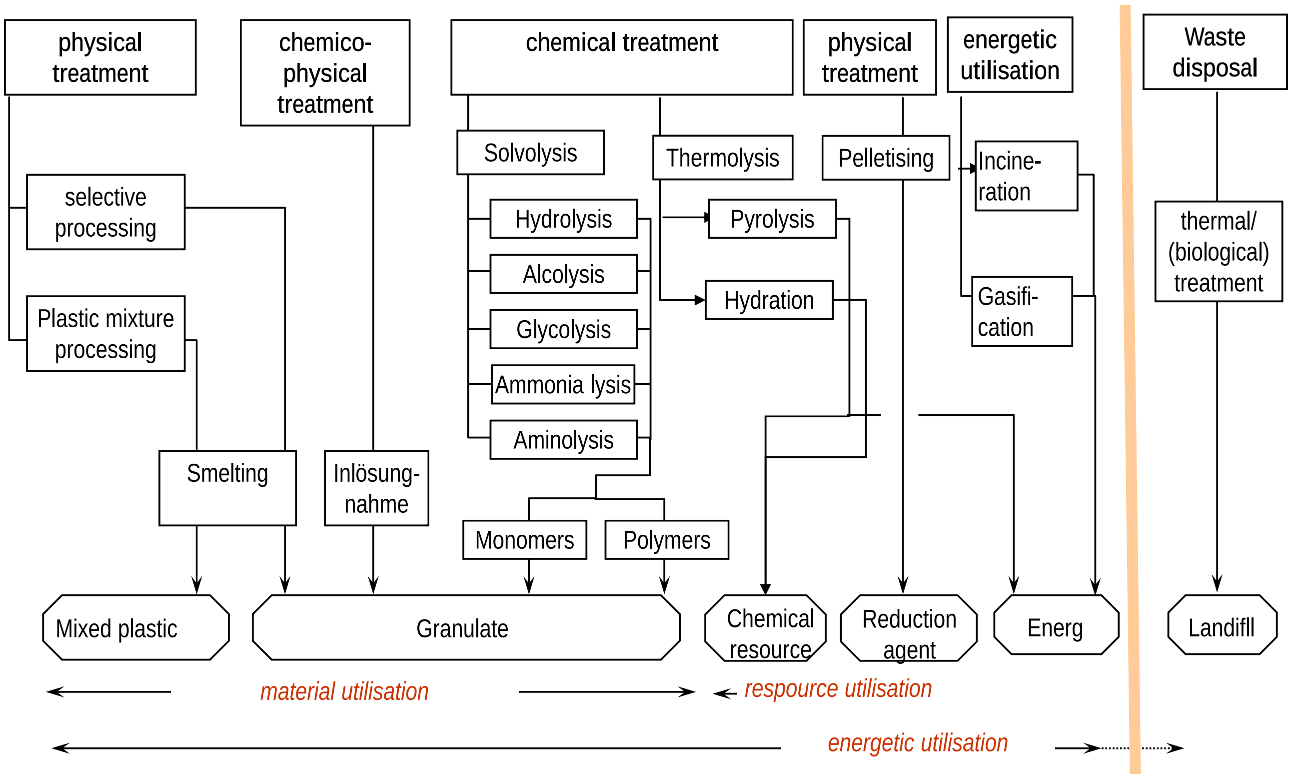
- Relevant for the **depositing and biological treatment** of waste:
  - the polymer structure of plastics is generally **not bio-degradable**, but single auxialary agents and fillers are (e.g. softeners), which may lead to the disintegration of the plastics.
  - according to TASi 1993, plastics cannot be deposited as the IL is GV > 5% and must thus be **energetically utilised or thermally treated**.
  - for **composting** or fermentation: plastics are screened as extraneous materials and otherwise utilised, also with bio-waste composting.
- Apart from the energetic utilisation of PVC-free plastics, the disposal of plastics is more problematic than that of paper waste or glass waste.

Biologically Degradable Plastics

- **Biologically degradable plastics** (bio-degradable substances **BDS)**; (DIN E 54900; NARAYAN; WESSLING, both in MENGES et al. (1992)):
  - purposeful working-in of labile points in the polymer chain
  - **photochemically degradable plastics** (disintegration under UV light)
  - **biologically degradable plastics**, e.g. on **cellulose** basis (cellulose diacetate foils, **PHB/V** (BEZ/HEYDE, 1996), **starch** or **polycaprolactone** (HÄRDTLE et al., 1991; PÜCHNER, 1994). Temperatures for biological degradation adjustable in a range from 20° to 60 °C.
  - Disadvantages of BDS
    - no ecologically high-grade utilistion; neither material nor energetic
    - high price; limited applicability

Trade name	Material	Supplier	on the market as	ca. price
Biopol	natural polyester from PHBV	Zeneca Bio Products	packaging; composting bags	12 €/kg
Bioceta	Cellulose acetate with softener	Franz Rascher GmbH &Co Chemiwewerkstatt KG	grave candles; packaging	6 €/kg
Flo-pak Bio8	extruded hydroxy-propylated starch	FLO-PAK GmbH	foamed as chips as packaging, padding	25 €/m³
MaterBi	Polyester/starch mixture	Novamont Sales; Europe Montesdison Deutschland	biros, ink ribbon cassettes; composting bags	1,5 – 4,5€/kg
Tone-Polymere	synthetic polyester from policaprolacton	Union Carbide Chem.		5,90 $/ kg
Renatur	extruded starch	Storpack; H. Reichenecker GmbH&Co	foamed chips as packaging padding	25 €/m³

Systematics of the Disposal Options for Plastic Waste according Härdtle, 1991; extended



Disposal Ways for Scrap Plastic with Priorities

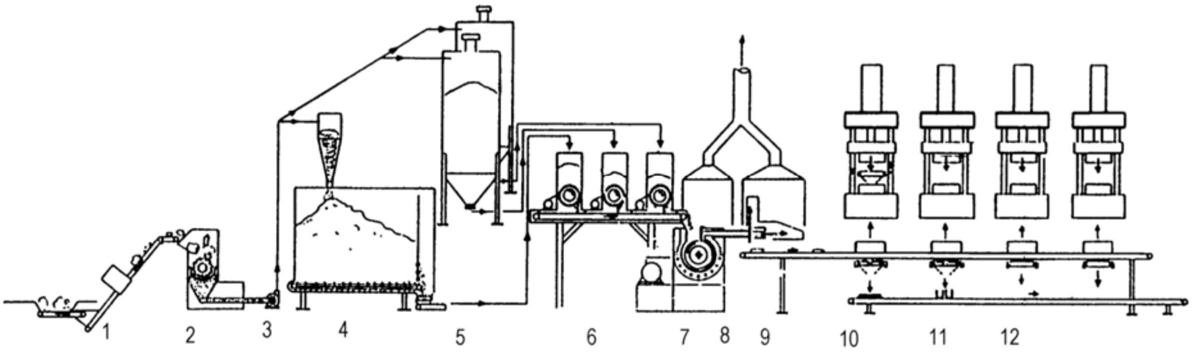
	DISPOSAL WAY	UTILISATION	RECOVERED PRODUCT
1. 2.	Re-granulation/ re-melting homogeneous plastics mixed plastics	**material**; macro-molecular structure; preservation of crucial ratios of the energetic efforts for production	Re-granulate, manufacturing into plastic products
3. 4.	Hydration Pyrolysis	**resources**; organic basic structure	Chemical resources; Gas and/or oils
5.	Incineration	**energetic**; caloric value	Energy
6.	Landfill	Dispensing with material and caloric value	--

Collection of Scrap Plastic

- SP from plastics production and other industries:
  large amounts of clean and sorted plastics.
- SP from households: low potential of ca. 15 to 25 kg/P·a,
  of which < 10 kg/P·a sales packaging covered by DSG
- SP **collection rates** from households:
  - **before** Packaging Ordinance 1991 only 20%-35%.
  - **after** Packaging Ordinance 1998: the utilisation quota of 60% was exceeded by far at 108% (!!) in 1999 (similar SP).
  - with DSG 97% (600,000 t /a)
- **Low bulk weight** of mixed SP of only 10-40 kg/m^3:
  → high collection costs in /t.
- Special collection systems for sorted qualities, for instance for
  - styrofoam recycling from trade and via municipal collection points with Big Bags for PS re-granulate,
  - agricultural foils via agricultural purchasing co-operatiaves,
  - telephone and bank cards; CDs (poly-carbonate PC)
  - PVC pipes and construction profiles.

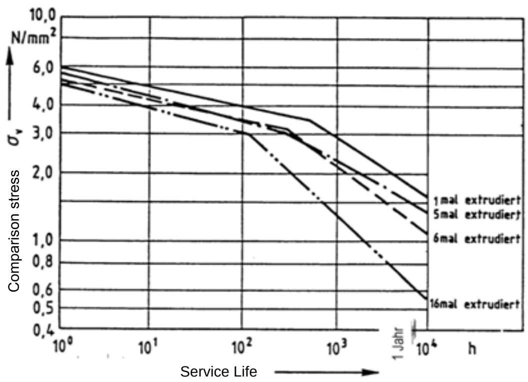
Material Utilisation of Mixed SP Plastics

- If the separation of the single types of plastics is dispensed with, simple process technology is available for the processing and re-moulding as „down"-cycling to mixed plastic products of low quality for underground construction and horticulture.



1	Mill feeding with metal separation	5	Mechanical conveyance	9	Plastifact dosage
2	Cutting mill	6	Dosing unit with rotary feeder	10	automatic press charging
3	Extractor fan	7	Plasticator	11	Pressing with cooled tools
4	Silo or container storage	8	Degassing unit/flue gas scrubber	12	automatic press discharge

Value-Saving Recycling of SP

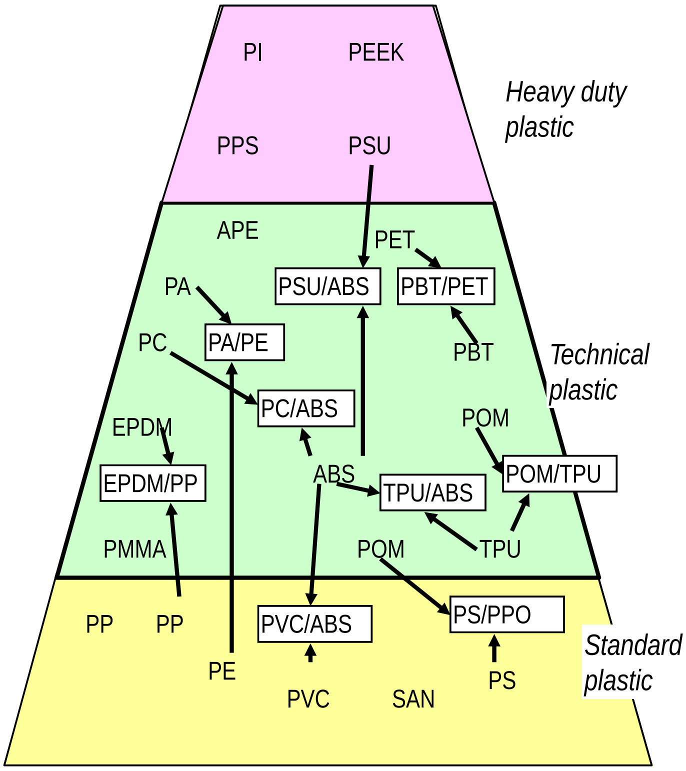


- Long-time rupture strength
- Compatibility of different plastics

	PS	SAN	ABS	PA	PC	PMMA	PVC	PP	PE-LD	PE-HD	PET
PS	1										
SAN	6	1									
ABS	6	1	1								
PA	5	6	6	1							
PC	6	2	2	6	1						
PMMA	4	1	1	6	1	1					
PVC	6	2	3	6	5	1	1				
PP	6	6	6	6	6	6	6	1			
PE-LD	6	6	6	6	6	6	6	6	1		
PE-HD	6	6	6	6	6	6	6	6	1	1	
PET	5	6	5	5	1	6	6	6	6	6	1

1 = easily mixable; 6 = hardly mixable

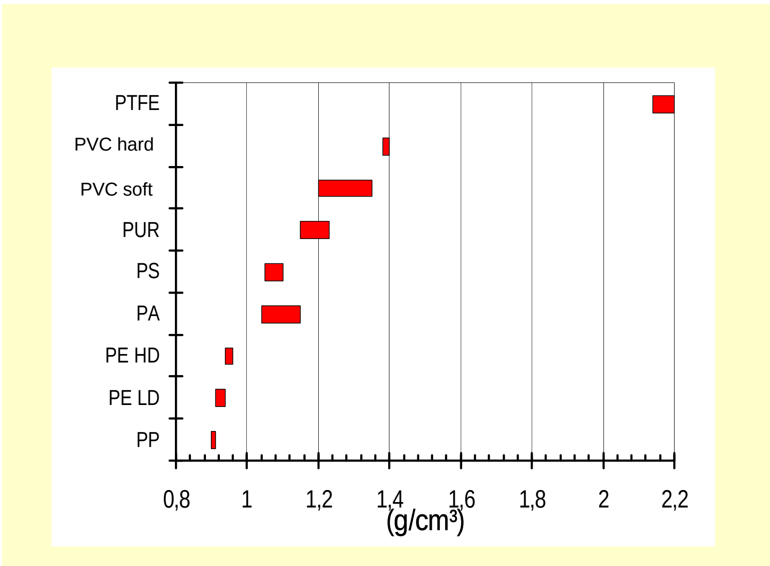
Value-Saving Recycling of SP – Miscibility and Blends



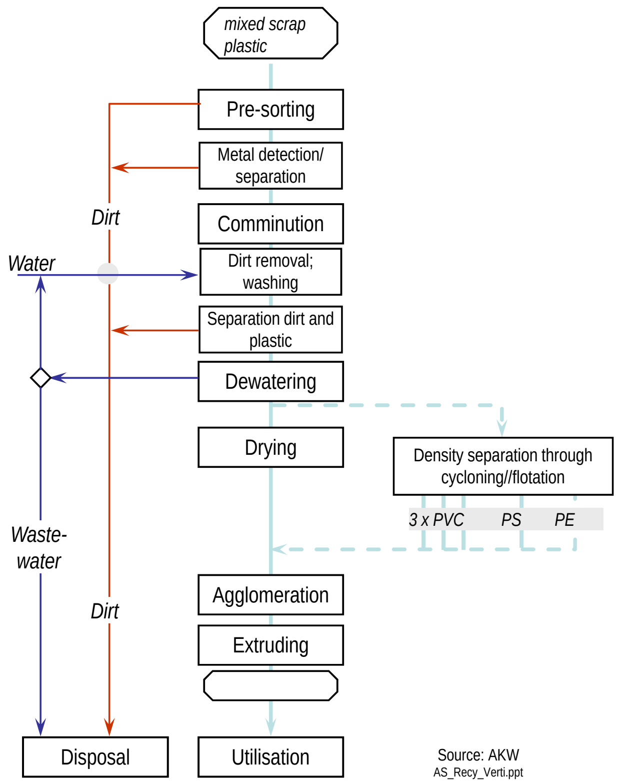
- no miscibility of standard plastics
- For special plastics, it is possible to produce co-polymerisates and blends by adding compatibility-inducing agents

Processing into Homogeneous SP (1)

- Up to 2000, the SP collected in the DSG were mainly separated into the following categories:
  - Foils
  - Hollow bodies, bottles
  - Cups, blisters
  - Foam
  - (Composites)
- Mechanical separation by density

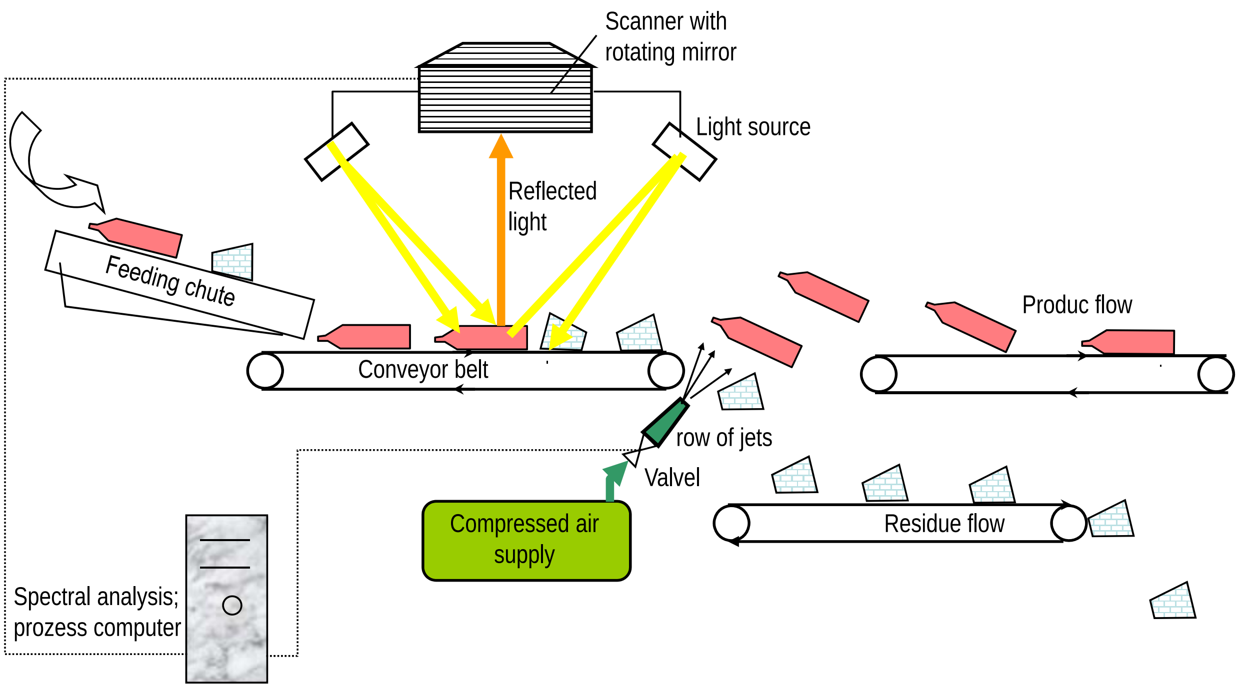


Processing into Homogeneous SP (2) - AKW-Method in Coburg

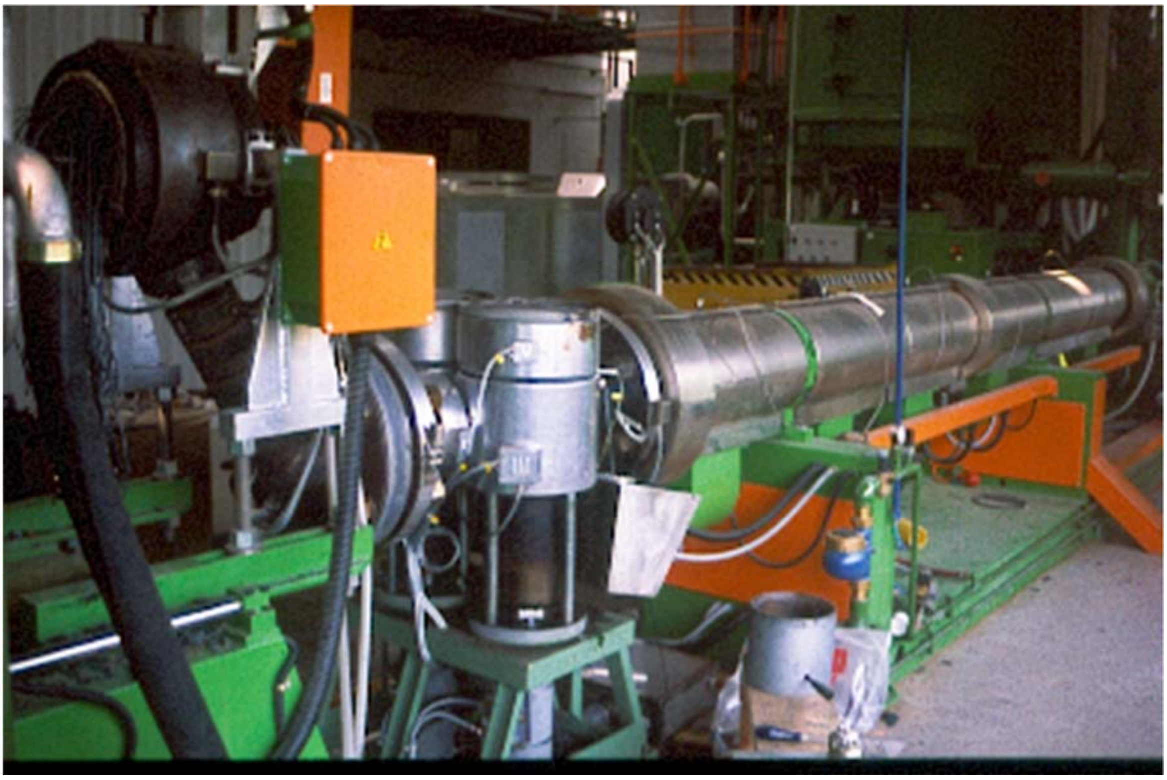


Source: AKW
AS_Recy_Verti.ppt

Processing into Homogeneous SP – Infra-Red (NIR-) Spectroscopy



Extruder



Chemical Recycling / Resource Utilisation

- As alternative to the material utilisation → resource utilisation with recovery of chemical resources, particularly oils, and partly also gases, through
  - **Alcolysis**, applied, for instance, to PUR foam or car seat scrap
  - **Hydrogenation**, e.g. in Coal-Oil-Plant Ltd. Company, Bottrop (KAB) → Comminuted and agglomerated DSG plastic is first dehalogenated to ca. 2000 ppm and then hydrogenated together with refinery vacuum residues at 300 bar hydrogen pressure and 475°C. → The resulting high-grade **Syncrude oil** is used in refineries as feedstock for the polymerisation.
  - **Dehalogenation** and ensuing **distillation** at **BASF** also runs with comminuted and agglomerated DSG plastic, first dissolved in plastic oil at 300° C, then degraded at 400° C through visbreaking and separated through distillation.
  - Preliminary **degradative extrusion** for degradation and dehalogenation with ensuing **steam cracking** Application of DSG plastics after mechanical processing or after degradative extrusion as **reducing agent in blast furnaces** (e.g. at the steel works in Bremen for 80.000 t/a) = resources recycling
  - **Pyrolysis** to produce chemical resources in the shape of gas and oil

Utilisation of Resources from Plastics in Blast Furnaces

Chemistry of the blast furnace process when plastics are used as additional reducing agent

Iron oxide reduction through synthetic gas

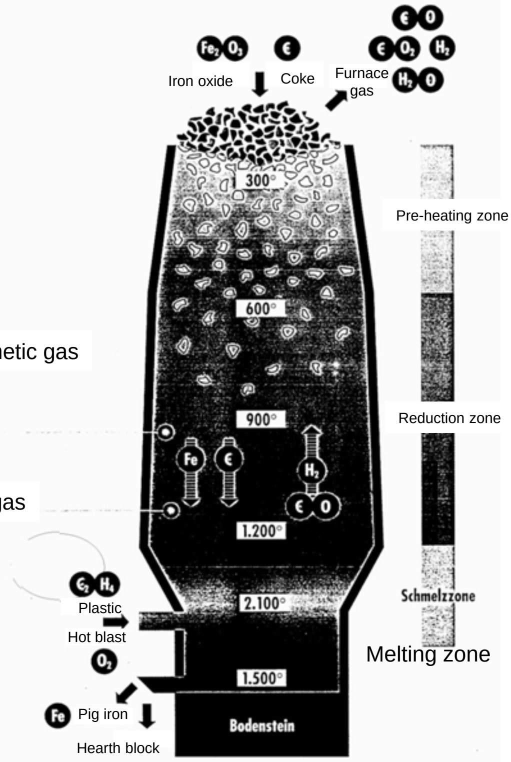
$Fe_2O_3 + 3\,CO = 2\,Fe + 3\,CO_2$

$Fe_2O_3 + 3\,H_2 = 2\,Fe + 3\,H_2O$

Cracking/production of synthetic gas

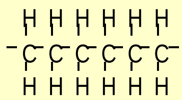
$C_2H_4 = 2\,C + 2\,H_2$

$2\,C + O_2 = 2\,CO$



Comparison of the Reaction Principles of Pyrolysis and Hydrogenation

according RAUSER, 1992 and LÖFFLER, 1989

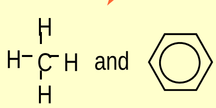


Pyrolysis

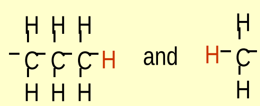
e.g. 700°C; O_2 elimination; pressure-less; distribution of H_2 according to chemico-physical laws

Hydrolysis

300°-500°C;
100 to 400 bar H_2;
cracking reaction with saturation of the ruptures with H_2



Methane, olefines, aromatics and coke

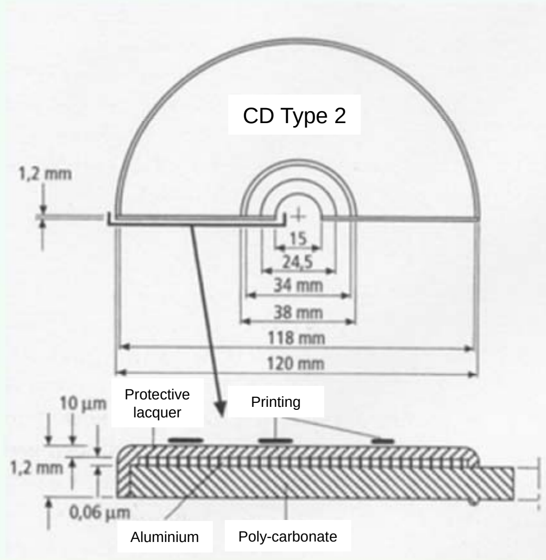


Preservation of chains

	Pyrolysis Weight %	Hydrogenation Weight %
Methane	23.1	1.1
Ethene	19.0	-
Gaseous hydrocarbons	20.5	7.0
Chain-like hdrocarbons	4.9	87.7
Benzene	16.6	0.2
Toluol, xyloles	7.8	0.2
Higher aromatics	8.1	-
High-boiling hdrocarbons	-	3.8

CD Recycling

- CDs accumulate at various stages during the production
- In the production of the pure poly-carbonate disk
- During the aluminisation
- During the varnishing
- Confiscation of illegal pressings



CD Recycling

- CD consist predominantly of poly-carbonate (more than 90%) and small amounts of aluminium and lacquers
  connection between poly-carbonate and aluminium

  For the separation of the three substance groups, the aluminium layer must be removed through dissolution

CD Recycling