Deliverable report

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Version management

V0.1	20/04/2020	First draft (for review by WP partners)
	30/04/2020	Review ITB
	08/05/2020	Review ICT
V0.2	15/05/2020	Second draft
V0.3	26/05/2020	Third draft after revision by all partners

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1 INTRODUCTION AND OBJECTIVES

This deliverable defines the processes and products to be evaluated in the LCA and LCCA (Task 6.1 Life Cycle Inventory), at the beginning of the project from the recyclers, technology developers, and end-users (manufacturers of demonstrator parts).

Life cycle inventory (LCI) analysis is defined by ISO (14040 and 14044 standards) as the "*phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle*".
Life cycle inventory analysis involves quantifying the different flows from and to nature for a product system.
It determines the quantitative values of the materials and the energy inputs and outputs with co-products, wastes, and emissions to air, soil, and water of all process stages within the life cycle. This includes:

1. raw materials/energy needs;
2. manufacturing processes;
3. transportation, storage, and distribution requirements;
4. use and reuse; and
5. recycle and end-of-life scenarios.

The inventory is developed by using input and output data to construct *a flow model*. Data collection can be particularly time-intensive and resource-intensive because it must include all upstream processes (resources extraction, production, and transport) as well as downstream processes (product use and disposal).

Since the LCA / LCCA is a highly interactive process, it is expected that this report will be a "living document", i.e. the inventory of data for the LCA needs to be updated several times during the execution of the CREAToR project, supporting the development in the work-packages. Based on findings in the project, some extra requirements may be needed, or some requirements may become obsolete.

In order to clearly illustrate the analysis needs, the **material flow** has been analysed in M2 (July 2019), and updated at M3 (August 2019) and at M10 (March 2020) with the support of the partners involved. Information has been collected (from stage A1 to stage A3; from waste and material supply to manufacturing/processing technologies, respectively) from the partners for both, proposed product/process and each use case, and from WP 1, 2, 3, 4 and 5. Additional material data may need to be sourced, either from the literature, suppliers, or newly generated.
RWE has started internally the definition of the potential variables for each process, where different approaches (choice of materials, manufacturing process, etc) can be used, these will be defined for evaluation (data for the entire lifecycle will be collected).

2 MATERIAL FLOW

Material flow has been defined as *a systematic assessment of the flows and stocks of materials within a system defined in space and time'* (Brunner and Rechberger, 2003).
Materials flow analysis is a quantitative *procedure* for determining the flow of materials and energy through the economy. It uses input/output methodologies, including both material and economic information. It captures the mass balances in an economy where inputs (extractions + imports) equal outputs (consumption + exports + accumulation + wastes). Material flow asks whether the flow of materials is sustainable in terms of the environmental burden it creates.
The identification of waste is a major aspect of material flow as the purpose of conducting such an analysis is to minimize the flow of materials while maximizing human benefit generated by the flow. It allows the monitoring of wastes and economic analysis and is thus a useful method to evaluate the efficiency of the use of material resources. It is an important tool of industrial ecology and serves as the basis for material flow management. Material flow is a component of LCA and provides an in-depth snapshot in time of an aspect of LCA.

CREAToR utilises waste streams that are currently not reusable due to their contamination with health hazardous flame retardants, and due to economically non-viable collection, sorting and purification processes. In the initial sorting steps, novel sorting and identification technologies are applied, separating hazardous materials at the very beginning of the recycling process, immediately creating a novel, safe and valuable material streams to be exploited. It will overcome both problems by developing highly efficient continuous purification technologies (based on scCO2 and NADES/IL technology in twin screw extruders), together with new logistics and material flows to be implemented in products, processes and business models designed to maximise the value and utility of resources. By subsequent material optimisation and demonstration case studies in the automotive, building & construction, and aerospace industries, CREAToR will prove the reusability of currently landfilled and incinerated secondary raw material streams after undesirable, hazardous substances have been removed using the CREAToR purification technologies.

Below the material flow with separated charts for each individual process is presented. On each chart the short key is added although the general key is attached in the ANNEX (*Figure 1*).

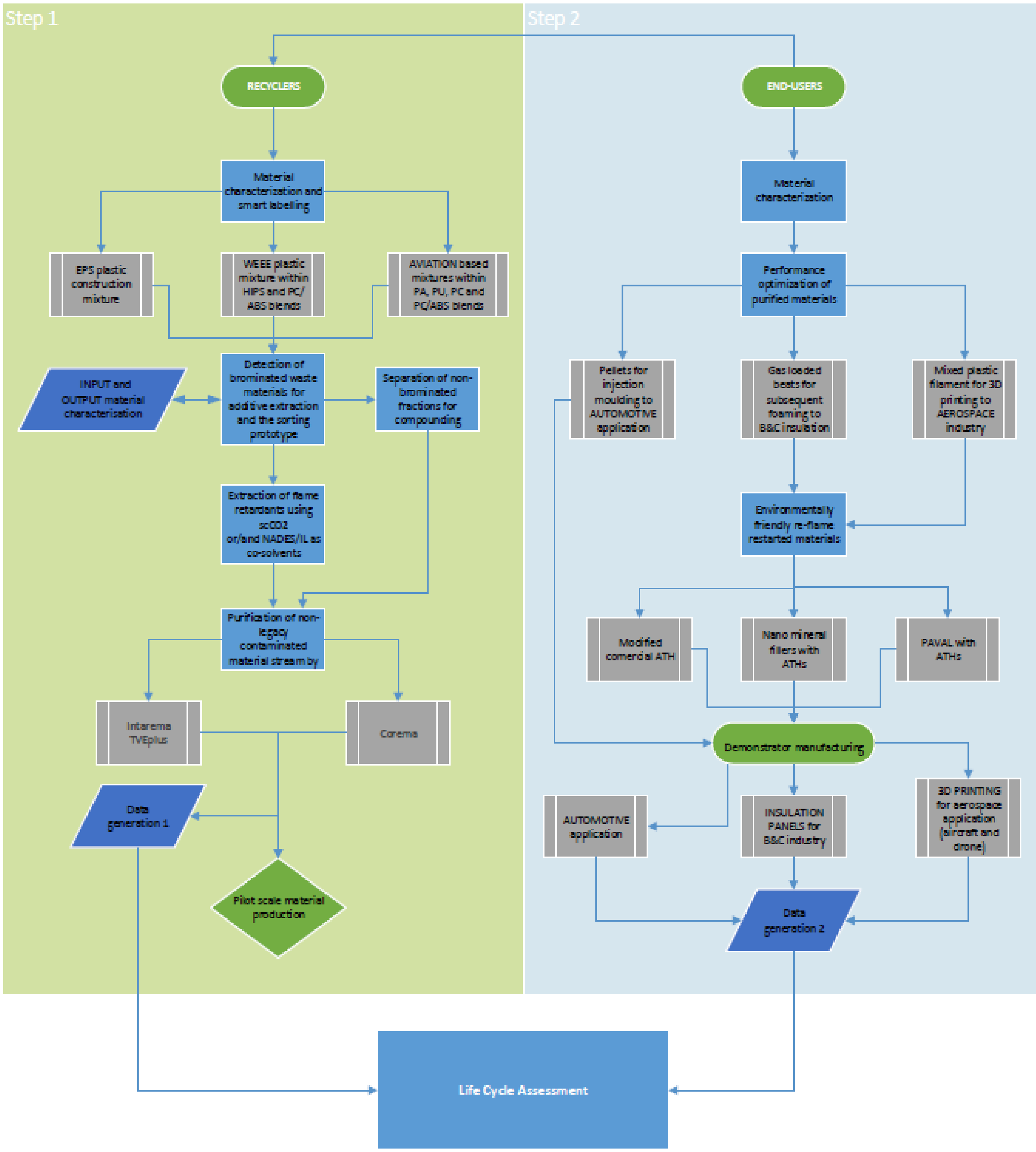


Figure 1. CREAToR`s Material Flow

2.1 MATERIAL CHARACTERIZATION AND SMART LABELLING

Material characterisation and online identification form the basis for the first removal of hazardous substances out of the waste stream by identification and sorting.

In this stage of CREAToR, the following partners are participating:

- recycler partners VLB, CLR, and REL;
- sorting line builder MOS;
- RTD partner GKR.

The bromine contents are in the range of around 0,6-1 wt% in pilot scale environments and 0,2 wt% in static tests (while some flame retardants are likely to be present in concentrations of 5-10 % in polymers that are flame retarded for WEEE applications).

2.1.1 EPS PLASTIC CONSTRUCTION MIXTURE

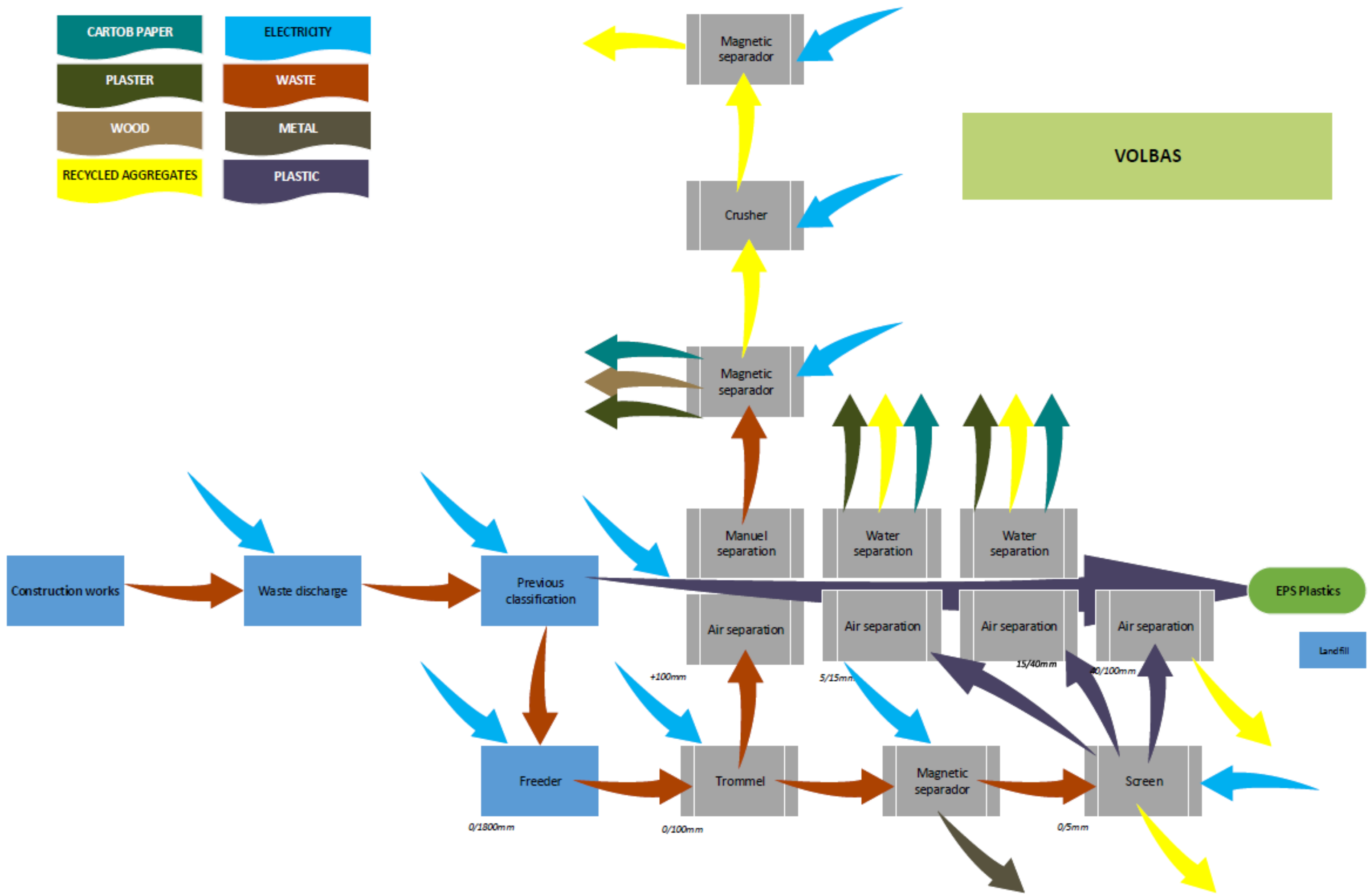
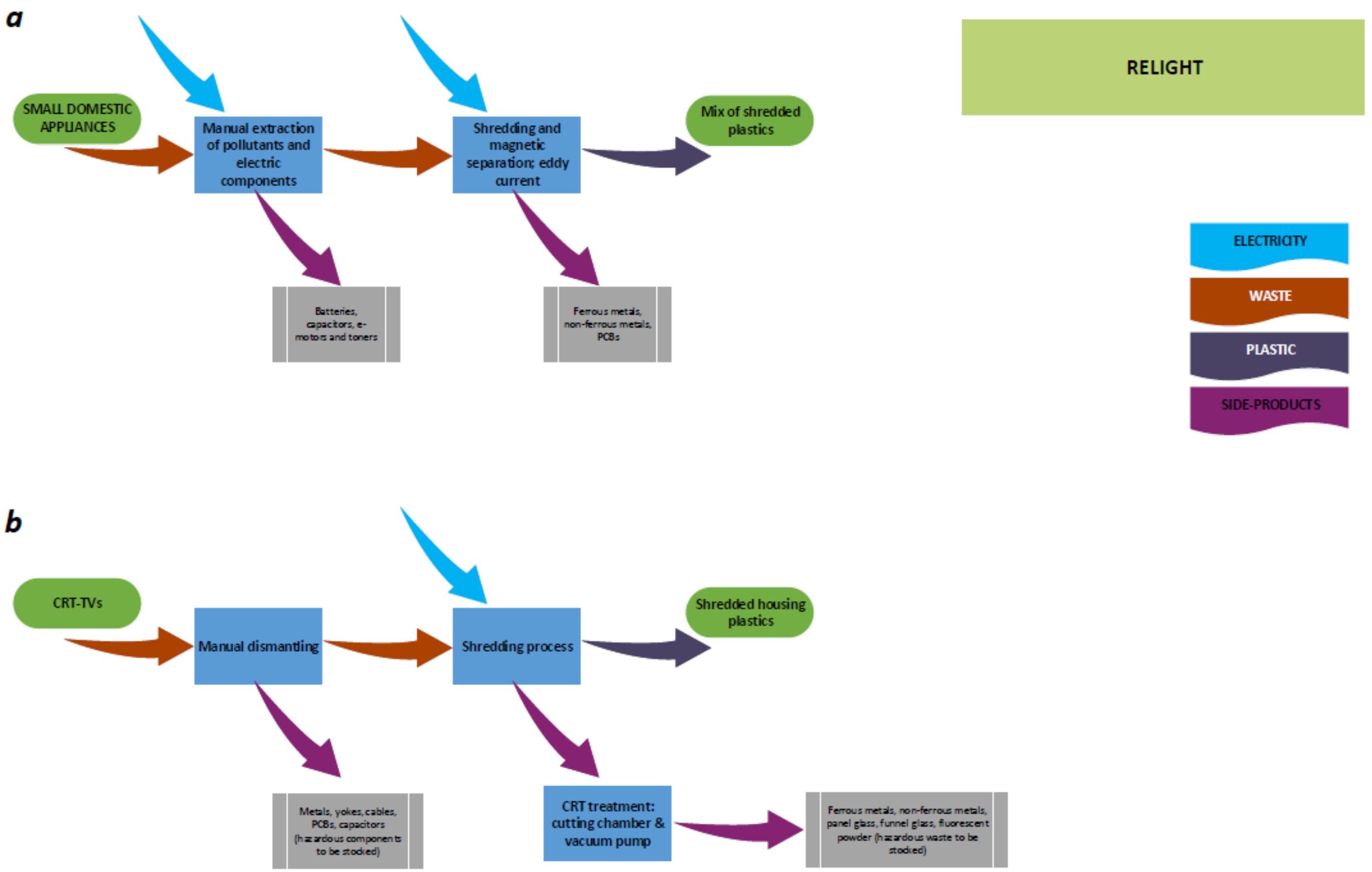


Figure 2. EPS plastic construction mixture by VOLBAS.

FLOWCHART	WEIGHT
Inputs: materials (contaminated construction materials), energy, water, pressurised air Outputs: materials (cartonpaper, plaster, wood, recycled aggregates), EPS, water, pressurised air	N/A

Table 1. Flowchart and Weight data for EPS plastic construction mixture.

2.1.2 WEEE PLASTIC MIXTURE WITHIN HIPS AND PC/ABS BLENDS



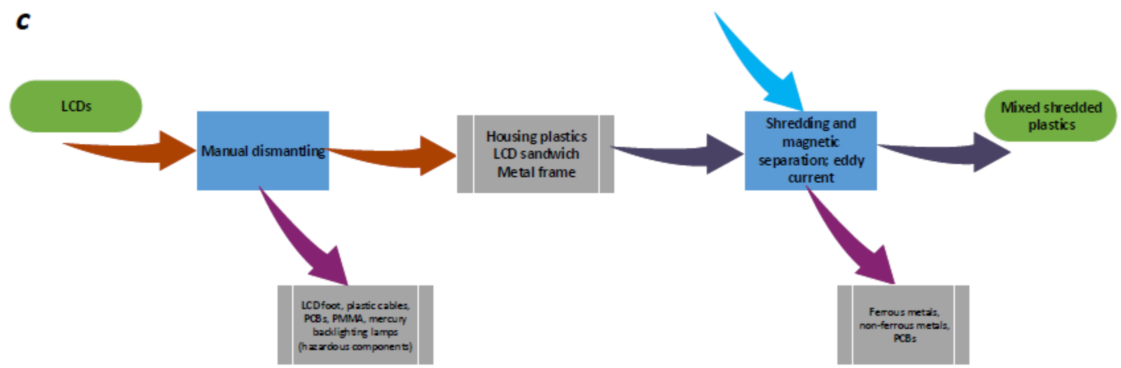


Figure 3. WEEE plastic mixture a) Small domestic appliances, b) CRT-TVs and c) LDCs within HIPS and PC/ABS blends by RELIGHT.

FLOWCHART	WEIGHT
Inputs: materials (small domestic appliances and screens), energy, water Outputs: materials (plastic rich fraction), water, gaseous emission	Plastic from SDA: 1000-1400 ton/y; plastic from CRT screens: 11000-14000 ton/y; LCD screen 2000-2200 ton/y

Table 2. Flowchart and Weight data for WEEE plastic mixture within HIPS and PC/ABS blends.

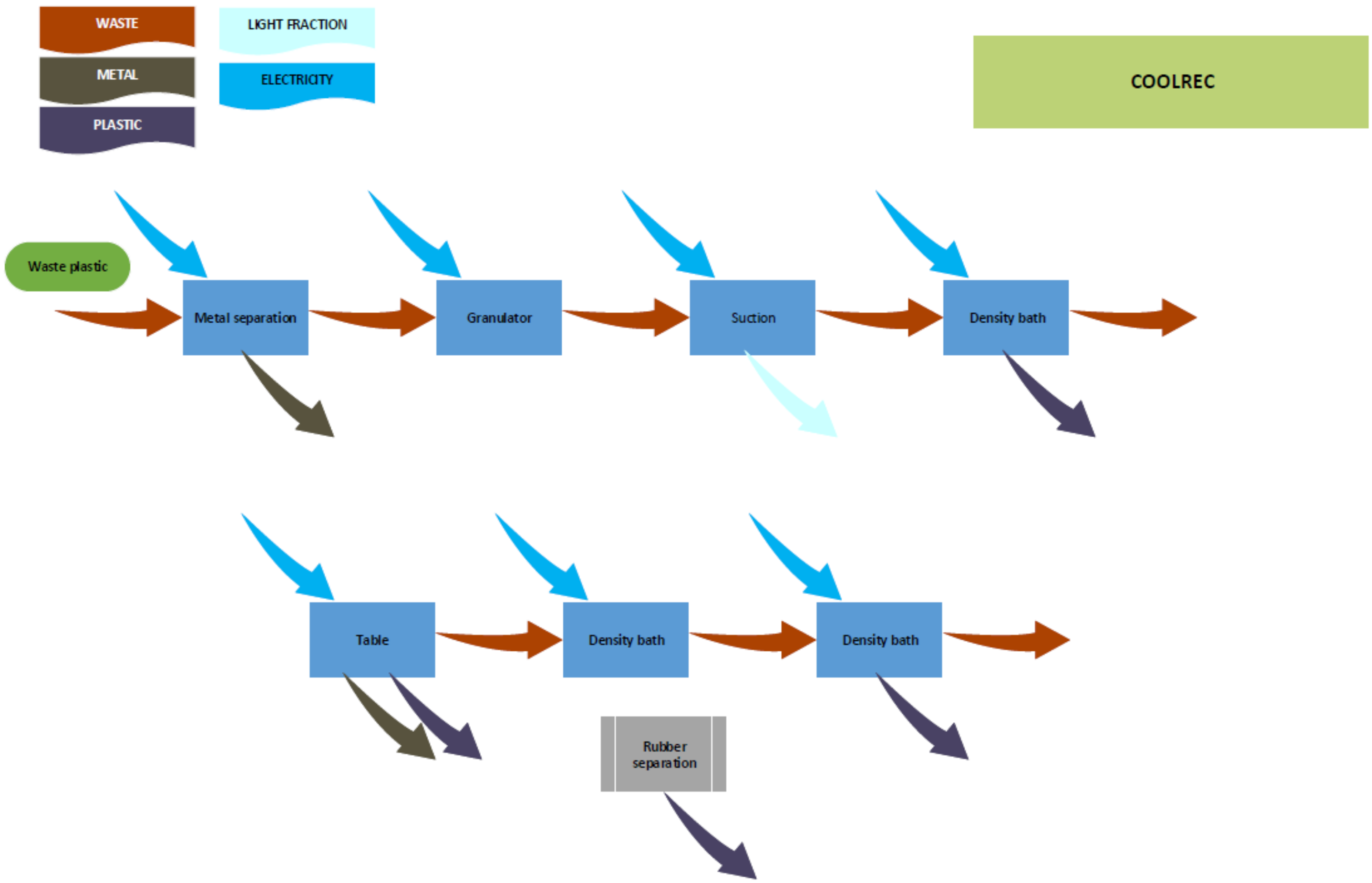


Figure 4. WEEE plastic mixture within HIPS and PC/ABS blends by COOLREC.

FLOWCHART	WEIGHT
Inputs: materials (Household fridge, small domestic appliance, ICT, professional fridge), energy, water Outputs: materials (plastic rich fraction), water, processing waste	Fridge:1220 ton/month SDA: 820ton/month ICT: 375ton/month Prof: 80ton/month

Table 3. Flowchart and weight data for WEEE plastic mixture within HIPS and PC/ABS blends.

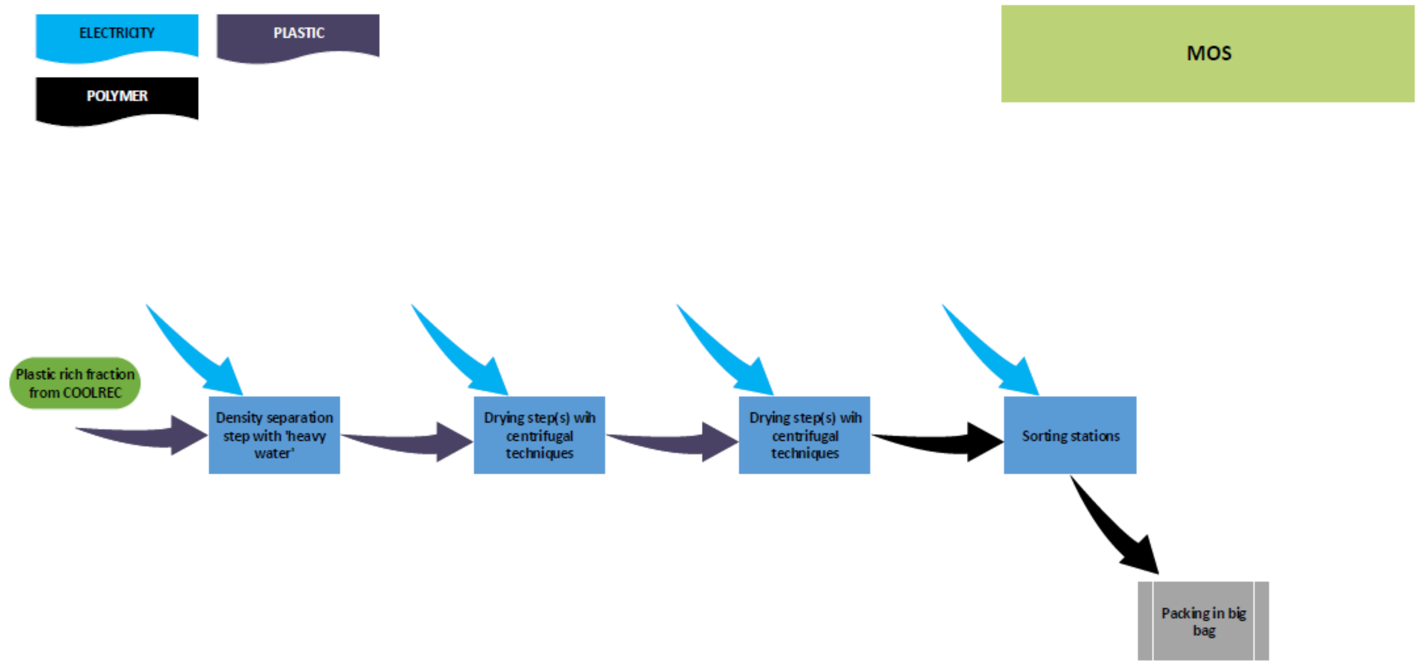


Figure 5. WEEE plastic mixture within HIPS and PC/ABS blends - SEPARATION by MOS.

FLOWCHART	WEIGHT
Inputs: materials (plastic rich fraction), energy, water, separation additives Outputs: materials (purified plastic), water, contaminated additives	Up to 1t/h

Table 4. Flowchart and weight data for WEEE plastic mixture within HIPS and PC/ABS blends - SEPARATION.

2.2 Detection of brominated waste materials for additive extraction and the sorting prototype

Partner GKR implements the laser-induced breakdown spectroscopy (LIBS) within CREAToR to measure the bromine content in EPS, HIPS, PA, PU, and PC/ABS waste polymers fractions (introduction a detection system into existing recycling processes). The technology innovation is tested using three waste streams from three different recycling sectors, enhancing the opportunities to increase the recycling rate and re-move brominated polymers by a common detection system.

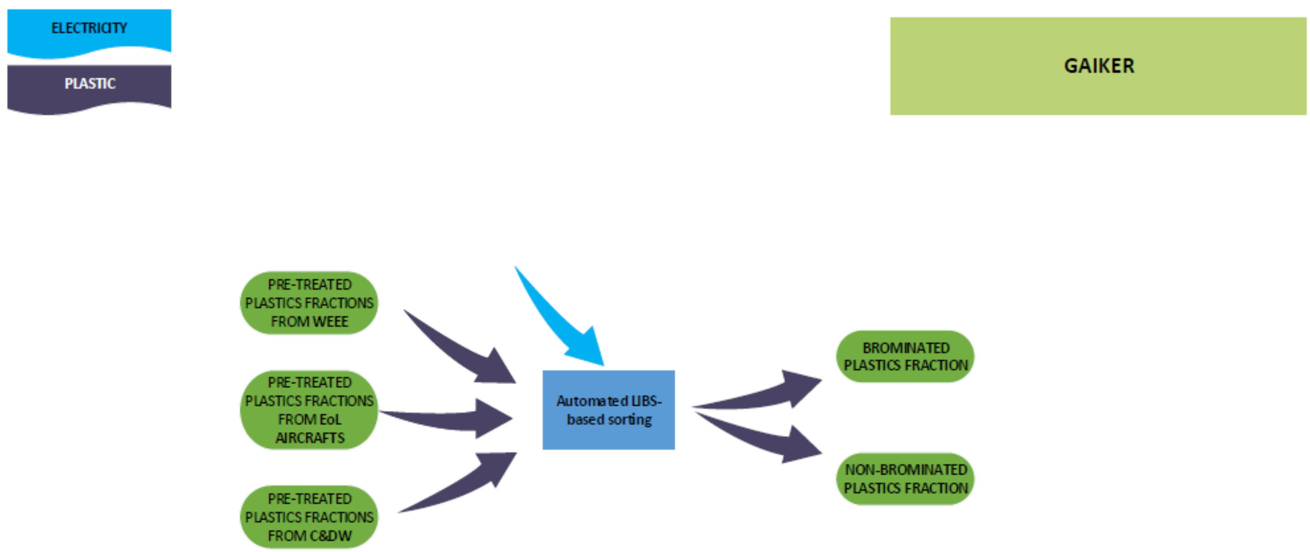


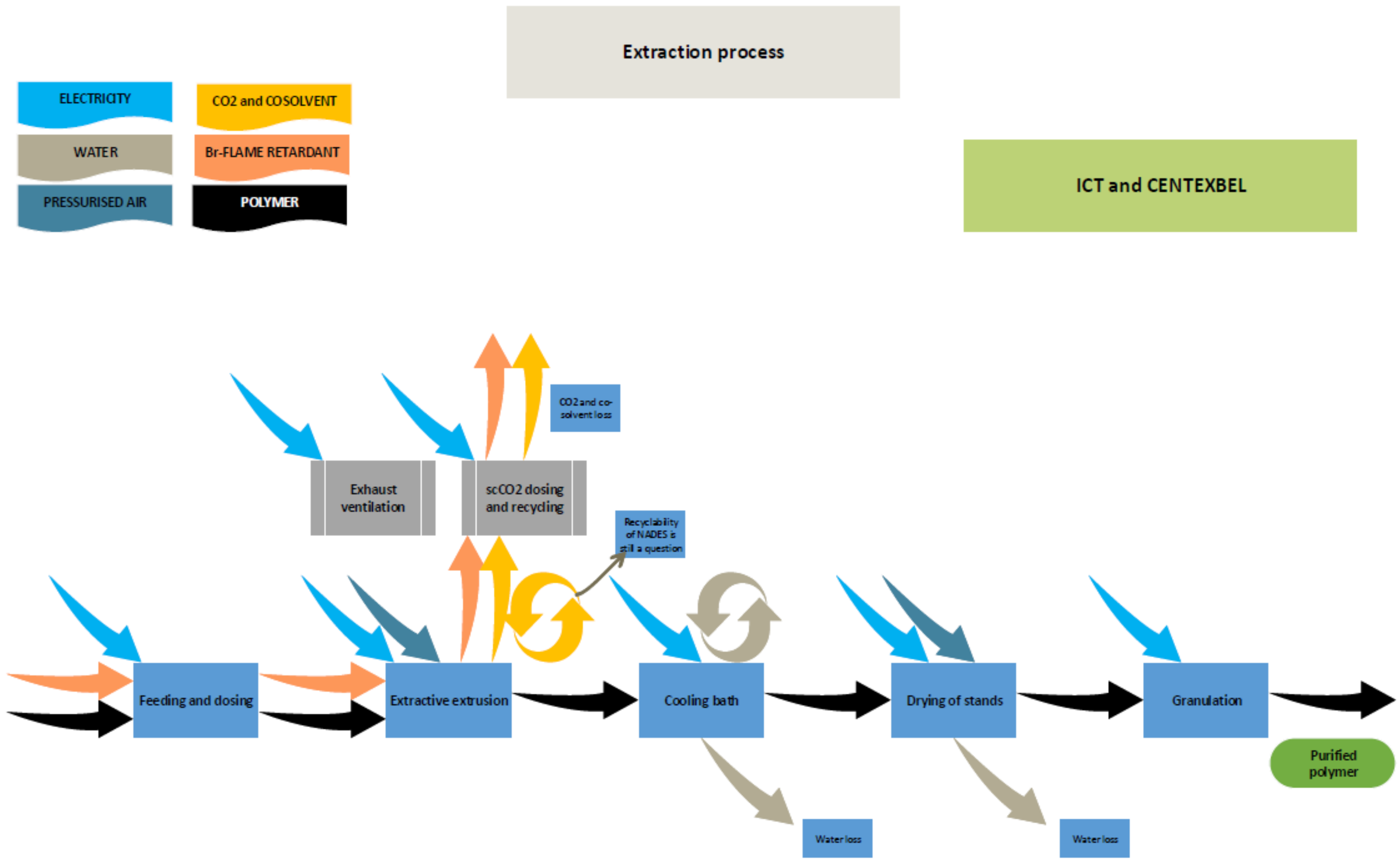
Figure 6. Detection of brominated waste materials for additive extraction and the sorting prototype by GAIKER.

FLOWCHART	WEIGHT
Inputs: pre-treated plastics fractions (HIPS, PC/ABS, ABS, EPS...) obtained by mechanical processing of WEEE, EoL aircrafts and C&DW, energy Outputs: non-brominated plastics fractions (Br< 0,1%) and brominated plastics fractions (Br≥0,1%)	n/a

Table 5. Flowchart and weight data for detection of brominated waste materials for additive extraction and the sorting prototype.

2.3 EXTRACTION OF FLAME RETARDANTS USING SCCO2 OR/AND NADES/IL AS CO-SOLVENTS

Two lines of technologies are followed and combined to remove flame retardants from the waste streams: the use of supercritical CO2 in twin screw extruders (ICT Fraunhofer) and the use of novel solvents (natural deep eutectic solvents (NADES) and/or ionic liquids (IL)) as cosolvents (CENTEXBEL) during extractive extrusion processes.



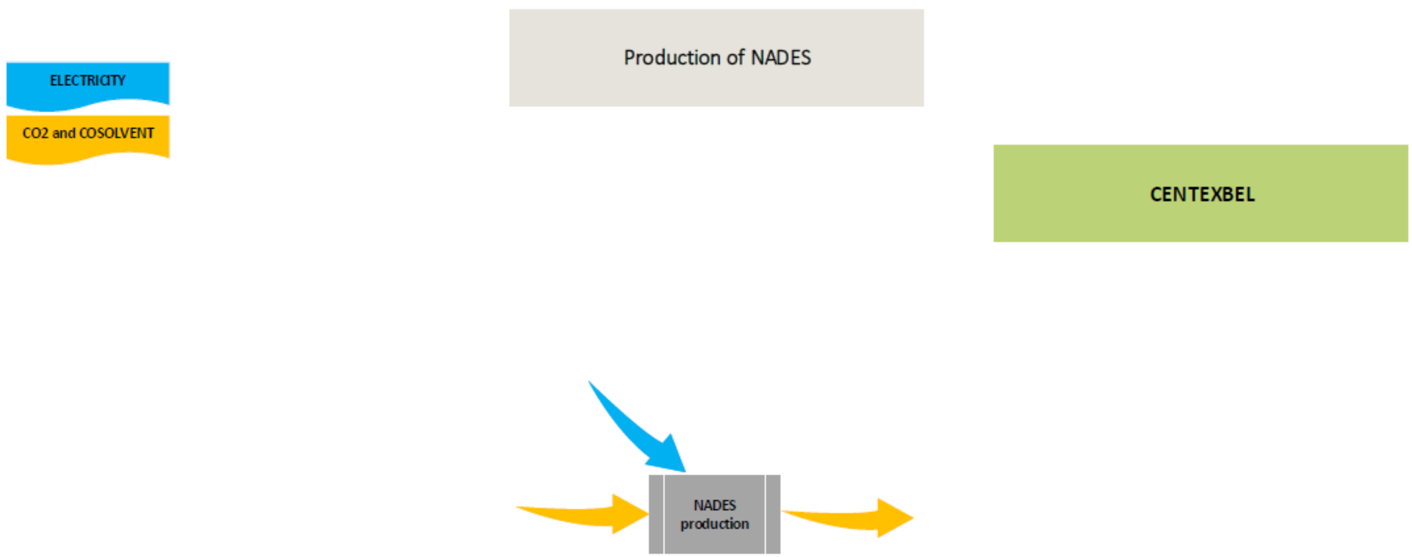


Figure 7. Extraction of flame retardants using scCO2or/and NADES/IL as co-solvents by ICT Fraunhofer and CENTEXBEL.

FLOWCHART	WEIGHT
Inputs: materials (contaminated polymers, solvents, CO2), energy, water, pressurised air Outputs: materials (purified polymer, contaminated solvents, contaminated CO2), dissipation energy, water, pressurised air	Throughput 1-2 --> 20 kg/h (polymer + CO2 + solvent)

Table 6. Flowchart and weight data for extraction of flame retardants using scCO2 or/and NADES/IL as co-solvents.

2.4 MONOFILAMENT EXTRUSION PROCESS

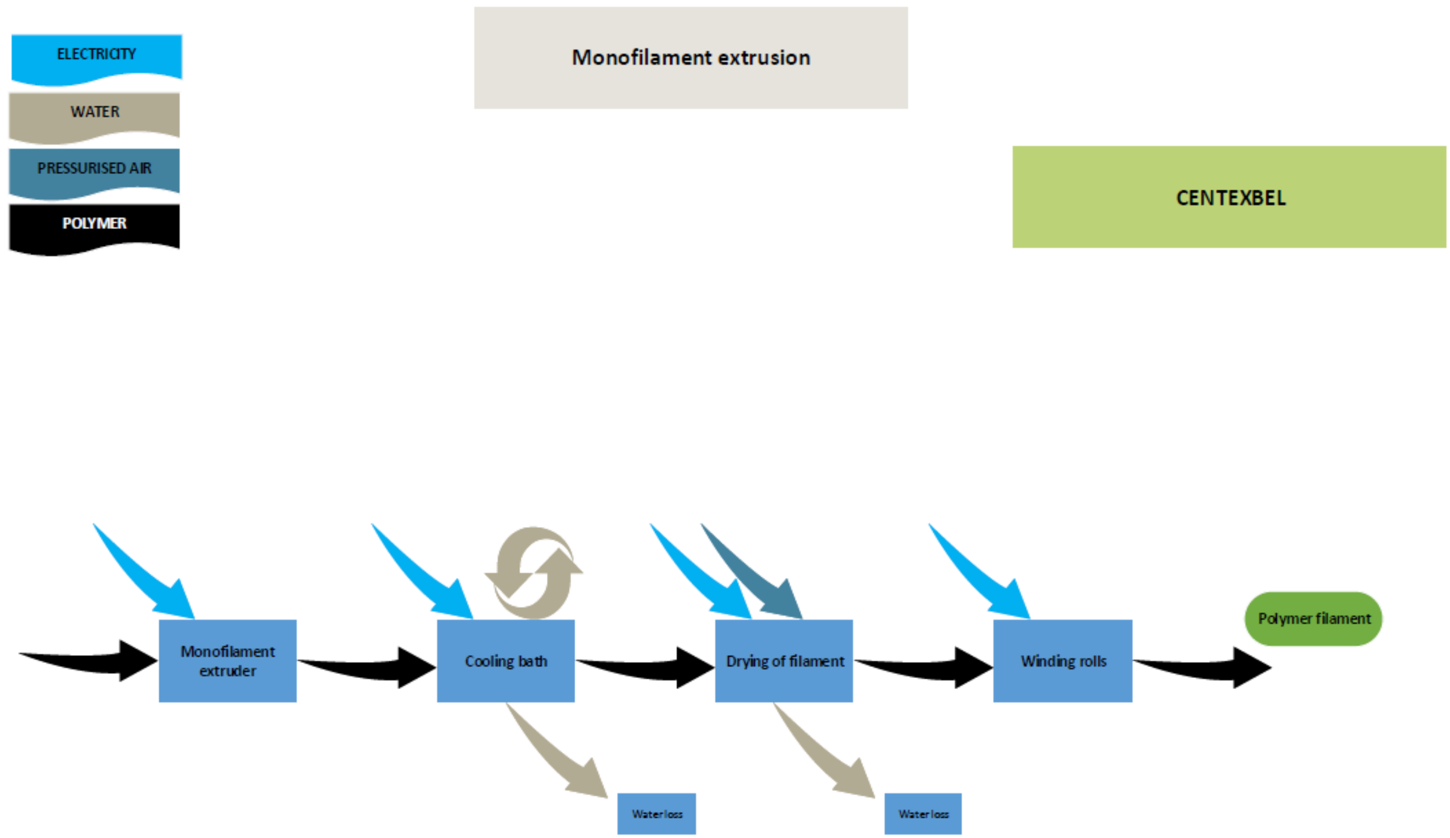


Figure 8. Monofilament extrusion process the purified material by CENTEXBEL.

FLOWCHART	WEIGHT
Inputs: materials (purified polymers), energy, water, pressurised air Outputs: materials (polymer filament), dissipation energy, water, pressurised air	Throughput 1-2 --> 20 kg/h (polymer)

Table 7. Flowchart and weight data for monofilament extrusion process.

2.5 PURIFICATION OF NON-LEGACY CONTAMINATED MATERIAL STREAM: INTAREMA OR COREMA

RMA develops rapid (*initial throughput of at least 300 kg/h*), effective (*option to circulate agent CO2*) and cost-efficient (*max. 1 €/kg additional costs*) processes to remove flame retardants from waste material streams. Due to the absence of environmentally and societally acceptable valorisation routes for bromine, the removed substances, being collected in highly concentrated form, will be safely disposed of by conventional routes.

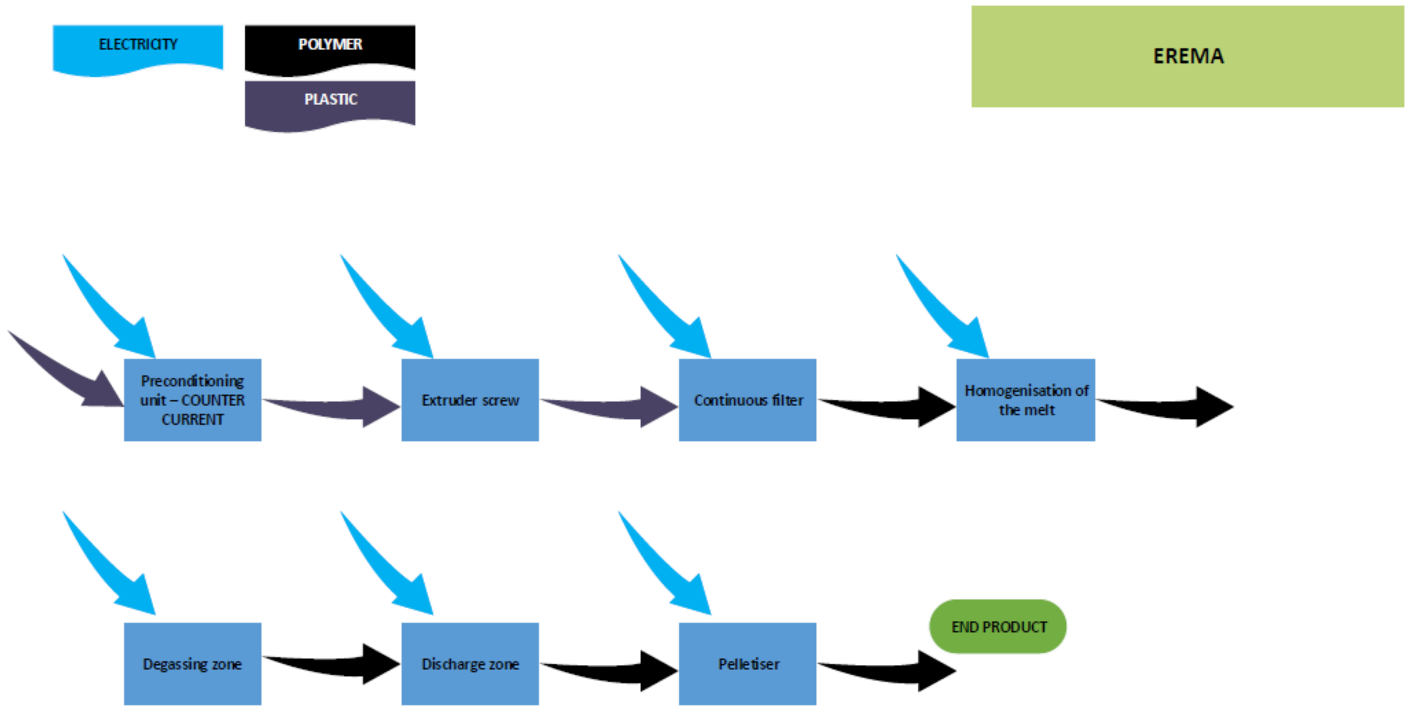


Figure 9. Purification of non-legacy contaminated material stream: INTAREMA or COREMA by EREMA.

FLOWCHART	WEIGHT
Inputs: regrind material, sorted and washed material, energy	@ recycler: depends on desired throughput; from 300 kg/h up to 4000 kg/h (without additivities); 24/7 processes are possible
Outputs: Pellets, input = output – filter discharge (minimal losses)	@ EREMA customer center: 300 – 500 kg/h

Table 8. Flowchart and weight data for purification of non-legacy contaminated material stream: INTAREMA or COREMA.

2.6 Performance optimization of purified materials

Reuse of the purified materials in automotive applications and applications requiring fire protection (3D printing and insulation foam).

2.6.1 Pellets for injection moulding to AUTOMOTIVE application

TCK works on the compatibilization of the WEEE fraction which allows this potentially heterogeneous fraction to be reused in the demanding automotive industry.

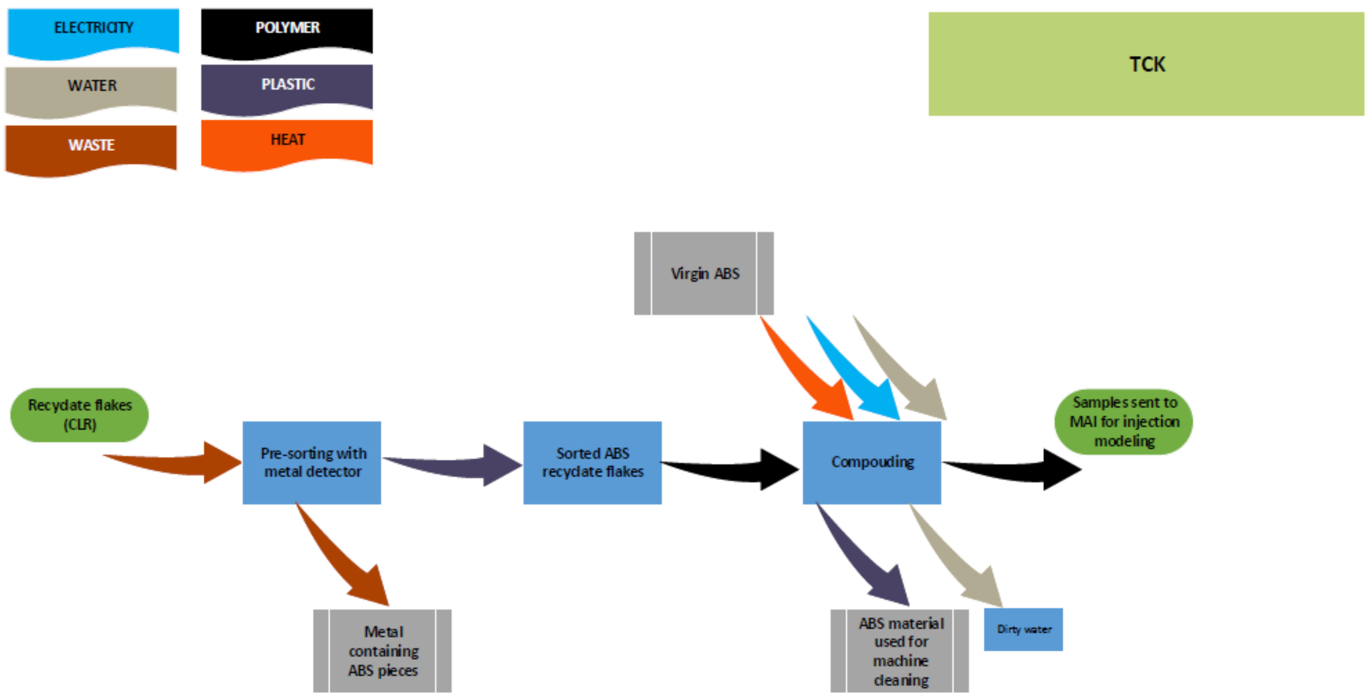


Figure 10. Pellets for injection moulding to AUTOMOTIVE application by TCKT.

FLOWCHART	WEIGHT
Inputs: materials (recycled flakes from COOLREC and virgin ABS from MAIER), energy, water, heat Outputs: materials (purified polymer, ABS material used for machine cleaning), water	n/a

Table 9. Flowchart and weight data for pellets for injection moulding to AUTOMOTIVE application.

2.6.2 GAS LOADED BEADS FOR SUBSEQUENT FOAMING TO B&C INSULATION

ICT Fraunhofer produces gas loaded beads made from recycled and purified polystyrene, to be utilised in the building and construction (B&C) industry as insulation materials, closing the loop of this material stream.

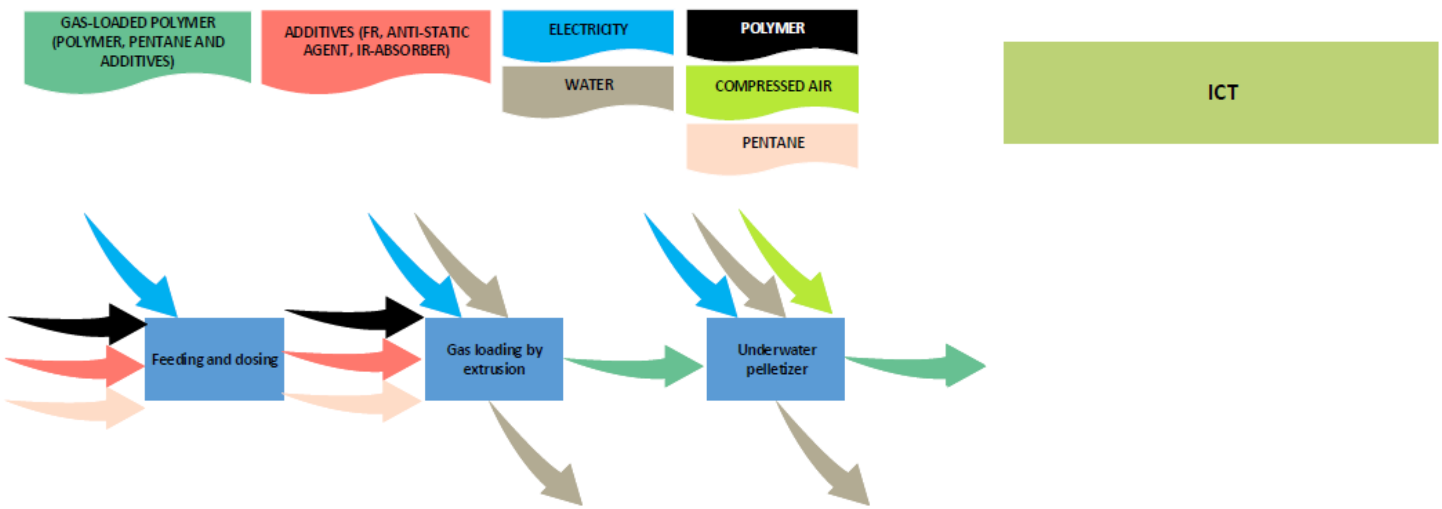


Figure 11. Gas loaded beads for subsequent foaming to B&C insulation and 3D printing by ICT.

FLOWCHART	WEIGHT
Inputs: materials (contaminated polymers, solvents, CO_2), energy, water, pressurised air Outputs: materials (purified polymer, contaminated solvents, contaminated CO_2), dissipation energy, water, pressurised air	Throughput 1-2 --> 20 kg/h (polymer + CO_2 + solvent)

Table 10. Flowchart and weight data for gas loaded beads for subsequent foaming to B&C insulation.

2.6.3 MIXED PLASTIC FILAMENT FOR 3D PRINTING TO AEROSPACE INDUSTRY

CENTEXBEL works in the filament production of the purified aviation sourced material streams, to care for proper processability in filament 3 D printing to be used in aerospace application.

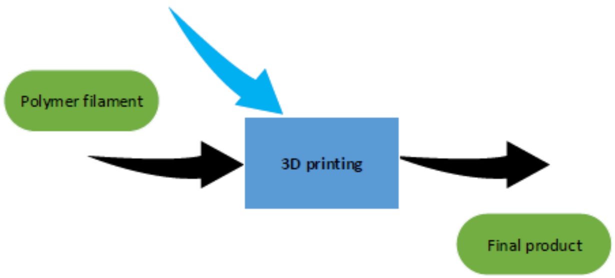


Figure 12. Mixed plastic filament for 3D printing to AEROSPACE industry by CENTEXBEL.

FLOWCHART	WEIGHT
Inputs: polymer filament, energy Outputs: material (plastic parts)	n/a

Table 11. Flowchart and weight data for mixed plastic filament for 3D printing to AEROSPACE industry.

2.7 ENVIRONMENTALLY FRIENDLY RE-FLAME RESTARTED MATERIALS

Partner CID investigates halogen free material formulations as flame retardant basing on two actuation lines: firstly, commercially remarkably interesting grades of ATH will be modified. These ATHs are present in other market applications and their attractive price would offer competitive advantages if they could be used for this purpose. Secondly, the use of other alternative additives based for example on the mineral PAVAL®, arising as secondary raw material stream from metallurgy itself, will be studied.

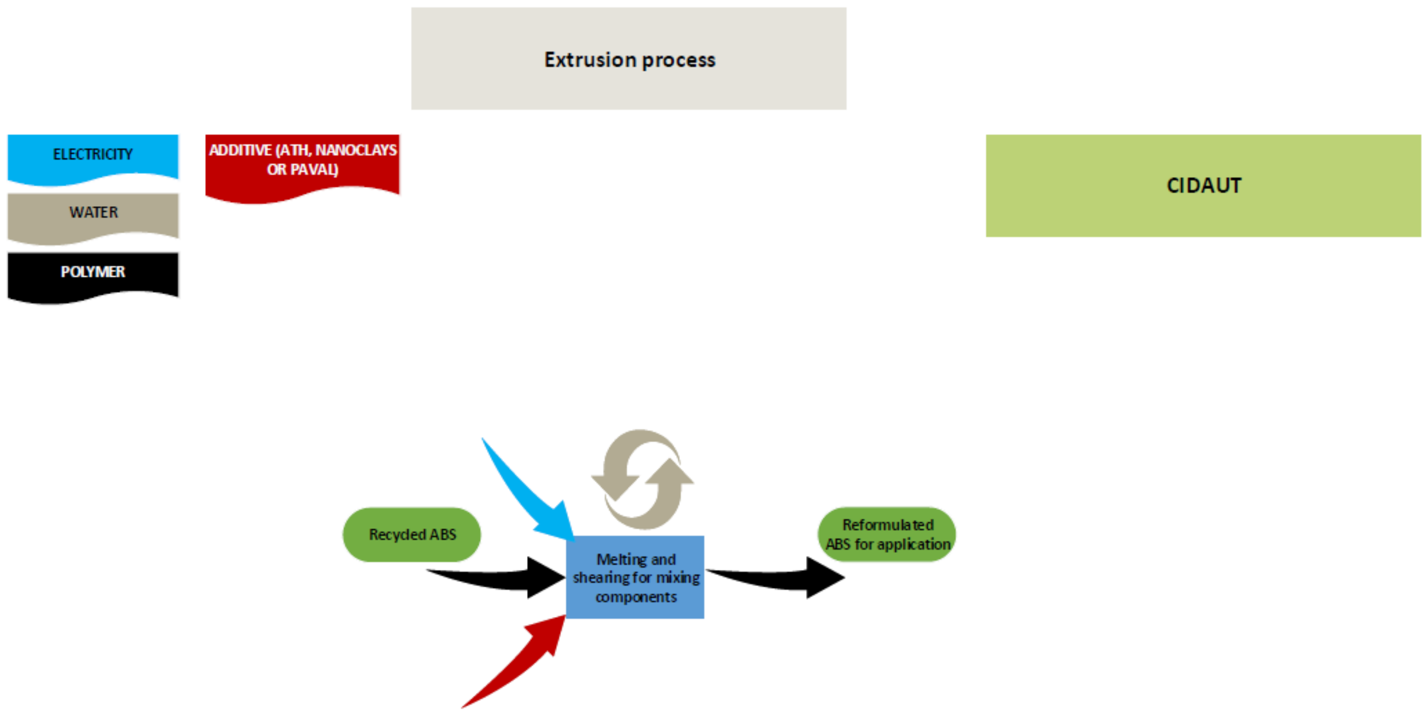


Figure 13. Environmentally friendly re-flame restarted materials by CIDAUT.

FLOWCHART	WEIGHT
Inputs: materials (recycled ABS/PC and recycled PS), additives: ATH, nanoclays or PAVAL), energy, water Outputs: materials (reformulated ABS/PC and reformulated PS), post-industrial recycled waste	n/a

Table 12. Flowchart and weight data for environmentally friendly re-flame restarted materials.

2.8 DEMONSTRATOR MANUFACTURING

The prepared secondary raw materials are transferred to the industrial end users MAI (ABS/HIPS for automotive application), DAW (PS for B&C), and CYC (3D printing for aerospace application).

DAW produces insulation panels for building and the construction industry, so closes the loop by introducing the collected polystyrene foams material back into its original application.

MAI uses the purified WEEE based materials in aesthetically decorated interior parts for automotive, substituting a share of their virgin production material by secondary raw materials.

An additional demonstration route covered in CREAToR by aerospace-experienced ITB together with company CYC is the use of high quality mixed plastics for 3D printing for aerospace applications.

2.8.1 AUTOMOTIVE APPLICATION

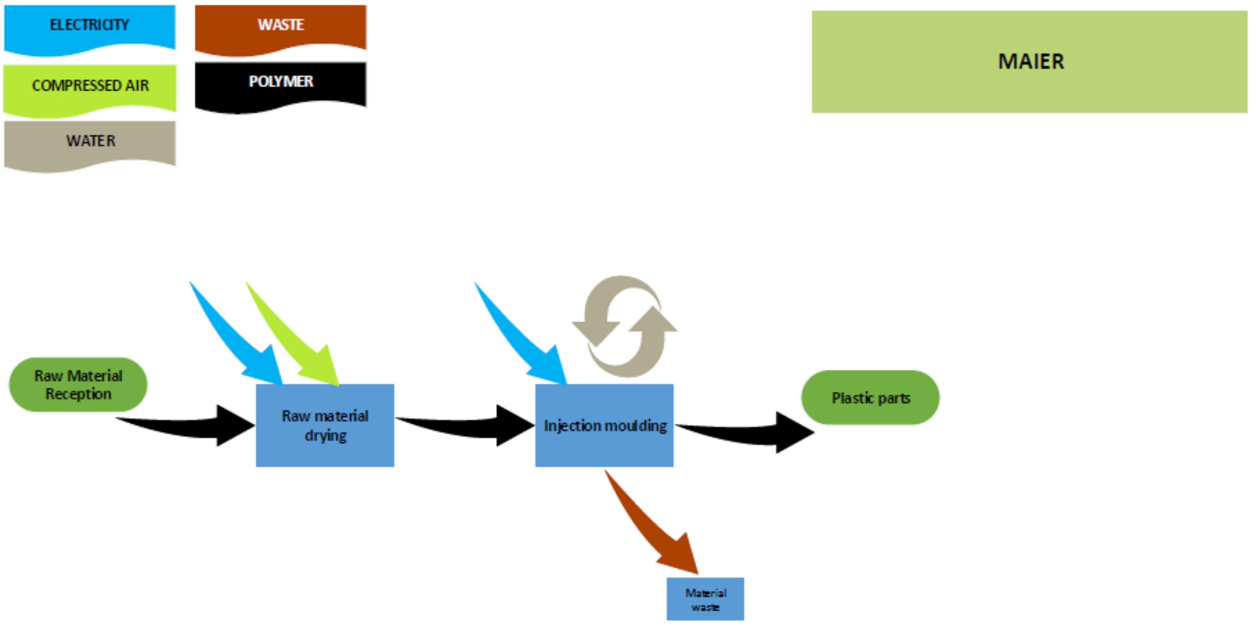


Figure 14. AUTOMOTIVE application by MAIER.

FLOWCHART	WEIGHT
Inputs: materials (ABS), energy, water, compressed air Outputs: materials (plastic parts), rejection of material during injection	0,03 Kg/part

Table 13. Flowchart and weight data for AUTOMOTIVE application.

2.8.2 INSULATION PANELS FOR B&C INDUSTRY

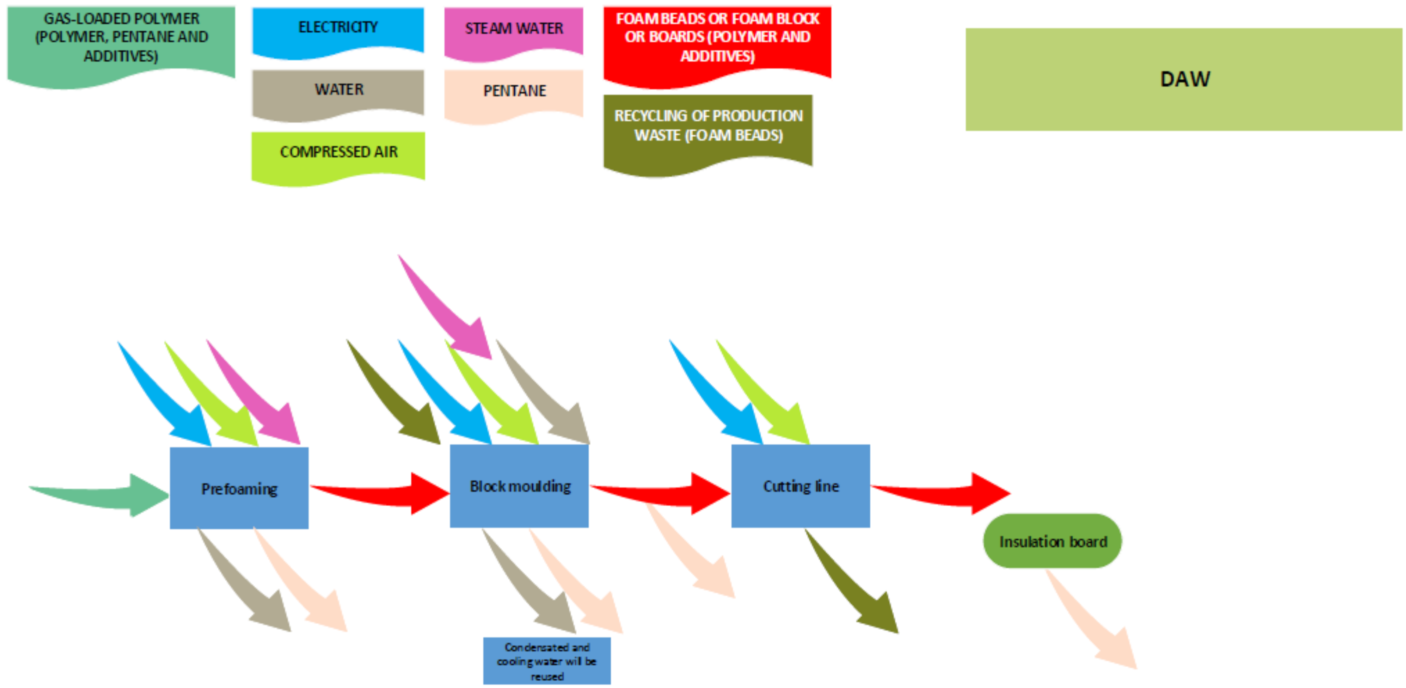


Figure 15. Insulation panels for B&C industry by DAW.

FLOWCHART	WEIGHT
Inputs: materials (polymer beads (purified EPS)), energy, water Outputs: materials (plastic parts), pentane, water	n/a

Table 14. Flowchart and weight data for insulation panels for B&C industry.

2.8.3 3D PRINTING FOR AEROSPACE APPLICATION (AIRCRAFT AND DRONE)

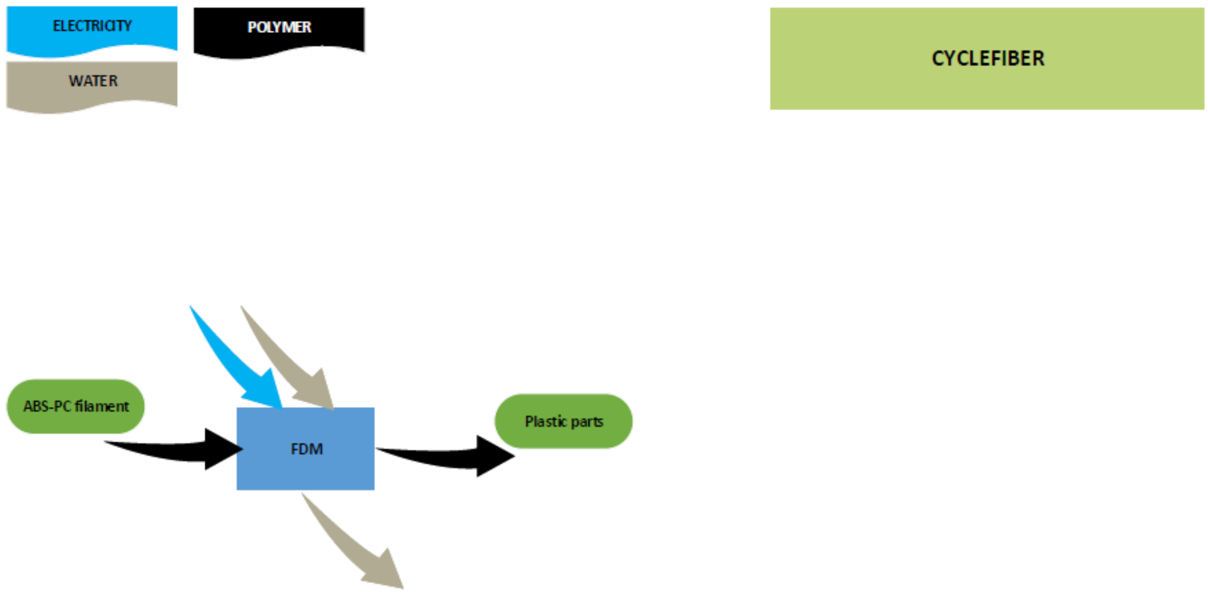


Figure 16. 3D printing for aerospace application (aircraft and drone) by CYC.

FLOWCHART	WEIGHT
Inputs: materials (ABS-PC filament), energy, water Outputs: materials (plastic parts), alkaline water (pH 11) as process output per part	0,03 Kg/part

Table 15. Flowchart and weight data for 3D printing for aerospace application (aircraft and drone)

3 LIFE CYCLE INVENTORY

Life Cycle Inventory analysis (LCI) is defined as a phase of Life Cycle Assessment (LCA) involving the compilation and quantification of inputs and outputs for a given product system throughout its life cycle (ISO 14040 1998a). LCI analysis involves creating an inventory of flows from and to nature for a product system. Inventory flows include inputs of water, energy and raw materials, and releases to air, land and water. To develop the inventory, a flow model of the technical system is constructed using data on inputs and outputs. The flow model is typically illustrated with a flow chart that includes the activities that are going to be assessed in the relevant supply chain and gives a clear picture of the technical system boundaries. The input and output data needed for the construction of the model are collected for all activities within the system boundary, including from the supply chain (referred to as inputs from the technosphere).
The data must be related to the functional unit defined in the goal and scope definition. Data can be presented in tables, and some interpretations can be made already at this stage. The result of the inventory is an LCI that provides information about all inputs and outputs in the form of elementary flow to and from the environment from all the unit processes involved in the study.

3.1 MATERIAL CHARACTERIZATION AND SMART LABELLING

3.1.1 EPS PLASTIC CONSTRUCTION MIXTURE

In Table 16 - Table 19, the inventory data are given for the EPS plastic construction mixture based on VOLBAS data.

Functional unit:	A1
Reference unit:	**EPS plastic construction mixture**
Consortium partner name	**VLB**
Date (DD/MM/YYYY)	11/11/2019
Manufacturing/Processing technologies place:	Erandio Bizkaia Spain
Life expectancy **(only for final products of project!)**	n/a

Table 16. General information about VLB` LCI state.

DESIGN AND ENGINEERING COST (€)	
MANUFACTURING/PROCESSING TOTAL COST (€)	14,80 E/ton
WASTE & MATERIAL COST (€)	Waste input (profit) 65,00 €/ton; Waste output (lost) 97,00 €/ton

Table 17. Cost information from VLB.

Component	Type of input	Description	Quantity	Unit	Costs (€)	Kilometers from provider to manufacturing place	Type of vehicle	Cost of the transport (€)	Comments
Component #1	Energy	electricity	1,52	kw/h	0,38 E/ton				

	Material	EPS			65,00 E/ton	17		118 E/on	
	Water	water	13,84	l/ton	0,057E/ton				
Component #2	Energy	diesel	0,92	l/ton	0,59 E/ton				

Table 18. Environmental inputs from VLB.

Type of output	Description	Quantity	Unit	Costs of treatment (€)	Kilometers to treatment plant	Type of vehicle	Cost of the transport (€)	Comments
Emissions to air	CO2 emissions	2,4	kgCO2/t0n					
Emissions to water		7,2	l/tn	0,053E/ton	0			
Other emissions/wastes	EPS			24 E/ton	42	truck	73,00 E/ton	

Table 19. Environmental outputs from VLB.

3.1.2 WEEE PLASTIC MIXTURE WITHIN HIPS AND PC/ABS BLENDS

In Table 20 - Table 23, the inventory data is given for WEEE plastic mixture within HIPS and PC/ABS based on RELIGHT data.

Functional unit:	A1
Reference unit:	**WEEE plastic mixture within HIPS and PC/ABS blends**
Consortium partner name	**REL**
Date (DD/MM/YYYY)	21/05/2020
Manufacturing/Processing technologies place:	Italy, Milan, RELIGHT PLANTS
Life expectancy (only for final products of project!)	n/a

Table 20. General information about REL` LCI state.

DESIGN AND ENGINEERING COST (€)	SDA line 1200 K€ - 800 K€ sorting/dismantling line for CrRT screens
MANUFACTURING/PROCESSING TOTAL COST (€)	SDA treatment: 110 €/ton - screens treatment: 95 €/ton
WASTE & MATERIAL COST (€)	Waste cost: 110 euros/ton

Table 21. Cost information from REL.

Component	Type of input	Description	Quantity	Unit	Costs (€)	Kilometers from provider to manufacturing place	Type of vehicle	Cost of the transport (€)	Comments
e-waste - S.D.A.	Energy	Electricity	280	kW/h	48 €/h				
	Material	WEEE - SDA	3	ton/h	100 €/ton				
e-waste - screens (CRTs)	Energy	Electricity	50	kW/h	8,50 €/h				
	Material	WEEE – CRT screens	7	ton/h					
e-wate - LCDs	Energy	Electricity	130	kW/h	22 €/h				
	Material	WEEE – LCD screens	1,5	ton/h					

Table 22. Environmental inputs from REL.

Type of output	Description	Quantity	Unit	Costs of treatment (€)	Kilometers to treatment plant	Type of vehicle	Cost of the transport (€)	Comments
Emissions to air	gaseous emmisions	44000	Nmc /h	5€/h				

Table 23. Environmental outputs from REL.

COOLREC inventory data for WEEE Plastic Mixture within HIPS and PC/ABS blends are confidential.

In Table 24 - Table 27, the inventory data is given for WEEE plastic mixture within HIPS and PC/ABS blends based on Machinefabriek Otto Schouten.

Functional unit:	A1
Reference unit:	**Sink-Float unit incl drying step**
Consortium partner name	**MOS**
Date (DD/MM/YYYY)	29/01/2020
Manufacturing/Processing technologies place:	Giessen The Netherlands
Life expectancy (only for final products of project!)	n.a.

Table 24. General information about MOS` LCI state.

DESIGN AND ENGINEERING COST (€)	€ 280.000
MANUFACTURING/PROCESSING TOTAL COST (€)	
WASTE & MATERIAL COST (€)	no waste costs, to be delivered by partner COOLREC costs of heavy water is around € 0,6/l

Table 25. Cost information from MOS.

Component	Type of input	Description	Quantity	Unit	Costs (€)	Kilometers from provider to manufacturing place	Type of vehicle	Cost of the transport (€)	Comments
Sink/floatline	Energy	Electricity	60	kWh /h	7.6 cents/ kwh				Electricity from the plant in Giessen
	Material	WEEE-plastics	Up to 1t/h	ton/ h	0 €				Partners within consortium CREATOR (e.g. Coolrec) delivers the plastics
	Water	Water	0,5	m³/h	9,4 cents /m³				Water coming from Brabant Water (local water supplier (normal drinking/tap water)
Separation additives	Material	Heavy water for separation of plastics			€ 0,6/l				Special Heavy water, with mixture with water density can be influenced on demand what density will be needed (between 1,00 up to 1,20).
	Material	Waste plastics/dustfraction -> incineration or landfill			€110/t on				Coolrec as partner will also get all separated materials/fractions back.
	Material	Waste water after lifecycle/end of use			€ 145/to n				Wasted water contaminated with different types of impurities like bromides, lithium, …… Classified as 'dangerous waste', to be treated by specialized waste collectors.

Table 26. Environmental inputs from MOS.

Type of output	Description	Quantity	Unit	Costs of treatment (€)	Kilometers to treatment plant	Type of vehicle	Cost of the transport (€)	Comments
Emissions to air		t.b.d.						CO2 emissions, small Particulates, NOx,…
Emissions to water		t.b.d.		€ 145/ton				Wasted water contaminated with different types of impurities like bromides, lithium, …... Classified as 'dangerous waste', to be treated by specialized waste collectors.
Emissions to soil		t.b.d.		€ 110/ton				All types of BFR's, Phosphors, rubbers, glass, minerals and other technical plastics, must be defined depending on the sort of WEEE.

Table 27. Environmental outputs from MOS.

3.1.3 AVIATION BASED MIXTURES WITHIN PA, PU, PC AND PC/ABS BLENDS

Data not available.

3.2 DETECTION OF BROMINATED WASTE MATERIALS FOR ADDITIVE EXTRACTION AND THE SORTING PROTOTYPE

In Table 28 - Table 31, the inventory data is given for the detection of brominated waste materials for additive extraction and the sorting prototype based on Fundacion Gaiker.

Functional unit:	A1
Reference unit:	**1 ton of input stream to be sorted out (Pre-treated plastics fractions)**
Consortium partner name	**GKR**
Date (DD/MM/YYYY)	08/11/2019
Manufacturing/Processing technologies place:	European Waste managers / recyclers facilities (GAIKER's premises during de project - Spain)
Life expectancy (only for final products of project!)	20

Table 28. General information about GKR` LCI state.

DESIGN AND ENGINEERING COST (€)	
MANUFACTURING/PROCESSING TOTAL COST (€)	300000
WASTE & MATERIAL COST (€)	

Table 29. Cost information from GKR.

Component	Type of input	Description	Quantity	Unit	Costs (€)	Kilometers from provider to manufacturing place	Type of vehicle	Cost of the transport (€)	Comments
Component #1 (automated LIBS-based sorting line)	Energy	Electricity	3	kWh/t-input	0,30 €				Electricity from grid. Estimated data for an industrial line (input= 1 t; power= 3 kW; capacity=1 t-input/h; energy cost for industrial use= 0,1 €/kWh)
	Material	Pre-treated plastics fractions (input)	1	t	0 €	0		0	The LIBS-based sorting line should be installed at the recyclers facilities, so in theory, the input (pre-treated plastics fractions) are produced in the same place (transportation of materials to be sorted is not considered)
									e.g. for description: Tap water, water from river,…

Table 30. Environmental inputs from GKR.

Type of output	Description	Quantity	Unit	Costs of treatment (€)	Kilometers to treatment plant	Type of vehicle	Cost of the transport (€)	Comments
	Output 1: Non-brominated plastics fractions (Br< 0,1%)	Data no available	t	0				Output fraction of the LIBS-based sorting process (amount depends on the contain of brominated plastics in the input stream) - to be recycled
	Output 2: brominated plastics fractions (Br≥0,1%)	Data no available	t	0				Output fraction of the LIBS-based sorting process (amount depends on the contain of brominated plastics in the input stream) - to be recycled

Table 31. Environmental outputs from GKR.

3.3 EXTRACTION OF FLAME RETARDANTS USING SCCO_2OR/AND NADES/IL AS CO-SOLVENTS

In Table 32 - Table 35, the inventory data is given for the extraction of flame retardants using scCO_2 or/and NADES/IL as co-solvents based on ICT and CTB data.

Functional unit:	A3
Reference unit:	**Extraction of flame retardants using sc-CO_2 or/and NADES/IL as co-solvents**
Consortium partner name	**ICT**
Date (DD/MM/YYYY)	04/11/2019
Manufacturing/Processing technologies place:	Fraunhofer ICT
Life expectancy (only for final products of project!)	30

Table 32. General information about ICT and CTB` LCI state.

DESIGN AND ENGINEERING COST (€)	200 000 € extrusion line with periphery equipment
MANUFACTURING/PROCESSING TOTAL COST (€)	50 ct-100 ct / kg
WASTE & MATERIAL COST (€)	CO_2 1 €/kg waste polymer 1 €/kg co-solvent 4 €/l NADES Disposal of flame retardants 300 €/kg

Table 33. Cost information from ICT and CTB.

Component	Type of input	Description	Quantity	Unit	Costs (€)	Kilometers from provider to manufacturing place	Type of vehicle	Cost of the transport (€)	Comments
Component #1	Energy	electricity for processing	1	kW/kg	0,06 €				electricity from grid
	Water	cooling water	0,1	L/kg	0,00 €				water
	Material	polymer	1	€/kg	1,00 €				
	Material	solvent	50	g/kg	0,20 €				
	Material	CO_2	2	kg/kg	2,00 €				
	Material	NADES	??CTB						

Table 34. Environmental Inputs from ICT and CTB.

Type of output	Description	Quantity	Unit	Costs of treatment (€)	Kilometers to treatment plant	Type of vehicle	Cost of the transport (€)	Comments
Emissions to air	N/A							
Emissions to water	N/A							
Emissions to soil	N/A							
Other emissions/wastes	disposal HBCD	10	g/kg	0,30				

Table 35. Environmental outputs from ICT and CTB.

3.4 PURIFICATION OF NON-LEGACY CONTAMINATED MATERIAL STREAM: INTAREMA OR COREMA

Data not yet available.

3.5 PERFORMANCE OPTIMIZATION OF PURIFIED MATERIALS

Data is not yet available for the demonstration cases:

- Pellets for injection moulding to AUTOMOTIVE application
- Gas loaded beads for subsequent foaming to B&C insulation
- Mixed plastic filament for 3D printing to AEROSPACE industry.

3.6 ENVIRONMENTALLY FRIENDLY RE-FLAME RESTARTED MATERIALS

In Table 36 - Table 39, the inventory data is given for environmentally friendly re-flame restarted materials based on Fundacion Cidaut data.

Functional unit:	A3
Reference unit:	**Environmentally friendly re-flame restarted materials**
Consortium partner name	**CID**
Date (DD/MM/YYYY)	22/05/2020
Manufacturing/Processing technologies place:	Additivation by extrusion process (new reformulated ABS/PC and new reformulated PS)
Life expectancy (only for final products of project!)	n/a

Table 36. General information about CID` LCI state.

DESIGN AND ENGINEERING COST (€)	n/a
MANUFACTURING/PROCESSING TOTAL COST (€)	n/a
WASTE & MATERIAL COST (€)	n/a

Table 37. Cost information from CID.

Component	Type of input	Description	Quantity	Unit	Costs (€)	Kilometers from provider to manufacturing place	Type of vehicle	Cost of the transport (€)	Comments
Reformulated ABS/PC with ATH	Recycled material	Recycled ABS/PC	0,8	kg	-				Unknow price of recycled ABS/PC
	Additive	ATH	0,3	kg	0,3				Estimated ATH Price: 1000€/ton
	Energy	Electricity	0,9	kWh	0,09				Estimated electricity (grid) price: 10 cnt / kWh
Reformulated ABS/PC with Paval	Recycled material	Recycled ABS/PC	0,8	kg	-				Unknow price of recycled ABS/PC
	Additive	Paval	0,3	kg	0,045				Estimated Paval Price: 150€/ton
	Energy	Electricity	0,9	kWh	0,09				Estimated electricity (grid) price: 10 cnt / kWh
Reformulated ABS/PC with Nanoclay	Recycled material	Recycled ABS/PC	0,8	kg	-				Unknow price of recycled ABS/PC
	Additive	Nanoclay	0,3	kg	0,24				Estimated Nanoclay Price: 800€/ton
	Energy	Electricity	0,9	kWh	0,09				Estimated electricity (grid) price: 10 cnt / kWh

Reformulated ABS/PC with ATH	Recycled material	Recycled PS	0,8	kg	-				Unknow price of recycled PS
	Additive	ATH	0,3	kg	0,3				Estimated ATH Price: 1000€/ton
	Energy	Electricity	0,9	kWh	0,09				Estimated electricity (grid) price: 10 cnt / kWh
Reformulated ABS/PC with Paval	Recycled material	Recycled PS	0,8	kg	-				Unknow price of recycled PS
	Additive	Paval	0,3	kg	0,045				Estimated Paval Price: 150€/ton
	Energy	Electricity	0,9	kWh	0,09				Estimated electricity (grid) price: 10 cnt / kWh
Reformulated ABS/PC with Nanoclay	Recycled material	Recycled PS	0,8	kg	-				Unknow price of recycled PS
	Additive	Nanoclay	0,3	kg	0,24				Estimated Nanoclay Price: 800€/ton
	Energy	Electricity	0,9	kWh	0,09				Estimated electricity (grid) price: 10 cnt / kWh

Table 38. Environmental inputs from CID.

Type of output	**Description**	**Quantity**	**Unit**	**Costs of treatment (€)**	**Kilometers to treatment plant**	**Type of vehicle**	**Cost of the transport (€)**	**Comments**
Other emissions/wastes	Post industrial waste	0,1 (each component)	kg	n/a(Recyclable)				Thermoplastic pellet: reusable for processing

Table 39. Environmental outputs from CID.

3.7 DEMONSTRATOR MANUFACTURING

3.7.1 AUTOMOTIVE APPLICATION

In Table 40 - Table 43, the inventory data is given for the automotive application based on MAIER data.

Functional unit:	A3
Reference unit:	**AUTOMOTIVE application**
Consortium partner name	**MAI**
Date (DD/MM/YYYY)	12/11/2019
Manufacturing/Processing technologies place:	Ajangiz, Spain
Life expectancy (only for final products of project!)	7-10

Table 40. General information about MAI` LCI state.

DESIGN AND ENGINEERING COST (€)	N.A.
MANUFACTURING/PROCESSING TOTAL COST (€)	N.A.
WASTE & MATERIAL COST (€)	N.A.

Table 41. Cost information from MAI.

Component	**Type of input**	**Description**	**Quantity**	**Unit**	**Costs (€)**	**Kilometers from provider to manufacturing place**	**Type of vehicle**	**Cost of the transport (€)**	**Comments**
PART 1	Energy	Consumption of the injection Machine+Raw material drying	320-360	Kw	45%				Consumption per Batch
	Material	ABS	0,03	Kg	55%	1500	Lorry		Delivery of 25Tn of material in a lorry
	Water	No real consumption							

Table 42. Environmental inputs from MAI.

Type of output	**Description**	**Quantity**	**Unit**	**Costs of treatment (€)**	**Kilometers to treatment plant**	**Type of vehicle**	**Cost of the transport (€)**	**Comments**
Other emissions/wastes	Rejection of Material during injection	4-7 %	Kg	N.A.	150	Lorry		Rejected material during injection is delivered to a treatment plant. 4-7 % is rejected per BATCH

Table 43. Environmental outputs from MAI.

3.7.2 INSULATION PANELS FOR B&C INDUSTRY

In Table 44 - Table 47, the inventory data is given for insulation panels for B&C industry based on DAW data.

Functional unit:	A3
Reference unit:	**EPS-conversion:** **Pre-foamer at DAW** **Block moulding at DAW** **Cutting at DAW**
Consortium partner name	**DAW**
Date (DD/MM/YYYY)	26/11/2019
Manufacturing/Processing technologies place:	DAW, Hirschberg
Life expectancy **(only for final products of project!)**	30

Table 44. General information about DAW` LCI state.

DESIGN AND ENGINEERING COST (€)	EPS-conversion: pre-foaming, blocking, cutting
MANUFACTURING/PROCESSING TOTAL COST (€)	n/a
WASTE & MATERIAL COST (€)	2,3 €/kg (this is the assumed price for the EPS made from recycled and purified EPS, at the moment!)

Table 45. Cost information from DAW.

Component	Type of input	Description	Quantity	Unit	Costs (€)	Kilometers from provider to manufacturing place	Type of vehicle	Cost of the transport (€)	Comments
Component #1	Energy	electricity for processing	0,058	kWh /kg	0,00 €				electricity from grid, 0,99 kWh/m³ (density EPS 17 kg/m³) --> 0,058 kW/kg
	Water	cooling water	0	l/kg	0,00 €				water is used in a cycle
	Material	polymer beads (purified EPS)	2,3	€/kg	1,15 €				
	Energy	water steam		g/kg	0,20 €				see electricity
	Energy	Oil	0,049	kg/kg					Oil for steam water

Table 46. Environmental inputs from DAW.

Type of output	Description	Quantity	Unit	Costs of treatment (€)	Kilometers to treatment plant	Type of vehicle	Cost of the transport (€)	Comments
Emissions to air	pentane	0,05	kg/kg	0	-	-	-	pentane diffusion during and after processing
Other emissions/wastes	loss water							e.g for description: wastewater, lithium bromide, … please, add a description of the type of treatment given.

Table 47. Environmental outputs from DAW.

3.7.3 3D PRINTING FOR AEROSPACE APPLICATION (AIRCRAFT AND DRONE)

In Table 48 - Table 51, the inventory data is given for 3D printing for aerospace application (aircraft and drone) based on CYCLEFIBER data.

Functional unit:	A3
Reference unit:	**3D PRINTING for aerospace application (aircraft and drone)**
Consortium partner name	**CYC**
Date (DD/MM/YYYY)	28/01/2020
Manufacturing/Processing technologies place:	Spain
Life expectancy (only for final products of project!)	7-10

Table 48. General information about CYC` LCI state.

DESIGN AND ENGINEERING COST (€)	N.A.
MANUFACTURING/PROCESSING TOTAL COST (€)	N.A.
WASTE & MATERIAL COST (€)	N.A.

Table 49. Cost information from CYC.

Component	Type of input	Description	Quantity	Unit	Costs (€)	Kilometers from provider to manufacturing place	Type of vehicle	Cost of the transport (€)	Comments
PART 1	Energy		250-430	MJ/part					
	Material	ABS-PC	3-5	kg/part	120-300 euro/part				
	Water		20	liters/part	negligible				

Table 50. Environmental inputs from CYC.

Type of output	Description	Quantity	Unit	Costs of treatment (€)	Kilometers to treatment plant	Type of vehicle	Cost of the transport (€)	Comments
Emissions to water	Alkaline water (pH 11) as process output per part	20	liters/part	?				

Table 51. Environmental outputs from CYC.

4 CONCLUSION

Life Cycle Analysis supports the assessment of best recycling practices and a sustainability screening of the purification processes for the waste streams covered by CREAToR. The practices at treatment facilities and identification of improvement mechanisms to promote the adoption of best practices throughout CREAToR implementation is also encouraged.

Inputs from WPs 1-5 to the LCA/LCC analysis allow investigation of the benefits of the CREAToR approach and inform subsequent developments in an iterative process. As the LCI is *a living document*, the data already collected can be, and even should be, continuously updated. Additionally, some partners have just started or are planning their activity, and it is quite difficult for them to deliver valuable data. This explains lack of data for some processes. Taking this into account, the LCI will be constantly revised and supplemented.

LCI and consequently LCA and LCCA allows environmental characterizations of technologies and products for up-scaled case studies. Application of these analysis in CREAToR permits the estimation of environmental impacts and highlights crucial processes to foster environmental improvements of the technologies and cost and techno-economic analysis of the envisaged technologies and products to foster uptake.

According to the life cycle inventory, LCA will determine environmental impacts of currently used manufacturing approaches and products and proposed project developments. Additionally, it will report ecological and human health impacts, and social and cultural impacts, in terms of materials (including life expectancy, number of cycles, and effects of using used modules/raw material), products (closed loop recovery rates and methods) and processes. The results will shape the development strategy within the project and finally substantiate the environmental credentials of developed processes and products.

5 ANNEXES

Participant list

Participant no.	Participant organisation name	Participant short name	Country
1	Fraunhofer Institute for Chemical Technology (Coordinator)	ICT	Germany
2	Volbas S.A.	VLB	Spain
3	Machinefabriek Otto Schouten BV	MOS	Belgium
4	Coolrec BV	CLR	Belgium
5	Relight SRL	REL	Italy
6	Fundacion Gaiker	GKR	Spain
7	Transfercenter für Kunststofftechnik GmbH	TCK	Austria
8	EREMA Engineering Recycling	RMA	Austria
9	Centexbel	CTB	Belgium
10	MAIER, S. Coop.	MAI	Spain
11	DAW SE	DAW	Germany
12	Cyclefiber S.L.	CYC	Spain
13	Fundacion Cidaut	CID	Spain
14	Kuhne Logistics University GmbH	KLU	Germany
15	Openbare Vlaamse Afvalstoffenmaatschappij	OVM	Belgium
16	RWEnergia Robert Wudarczyk	RWE	Spain
17	ITRB LTD	ITB	Cyprus

Key to material flows