CLEAN AVIATION

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18/10/2022

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AIRCRAFT RECYCLING AND CIRCULAR ECONOMY

Thomas Reichert, Peter Brantsch, Ronny Hanich-Spahn, Carl-Christoph Höhne, Fraunhofer

This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation program under grant agreements No945549.

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INTRODUCTION

Research for Recycling and Circular Economy has a long tradition in Fraunhofer. e.g. are the Circular Economy Symposia in the early 90-ies and the new Aircraft Recycling Symposia starting 2013.

What are the main tasks at the aircraft end of life?

1. decommissioning,
2. careful disassembly and
3. dismantling.

For economic and ecological reasons, the aim is to achieve the highest possible percentage of reuse and recycling rate.
In the case of recycling, a distinction is “differentiate between the use of secondary components and secondary raw materials”. Accordingly, a distinction can also be made between a component recycling quota and a material recycling quota.

Current aircraft achieve a recycling rate, based on mass, of between 60% and 85%, and the aim is to achieve more.

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Aircraft Metal Recycling

AiMeRe – CS1-EDA (2012-2014; ENVISA SAS, France)

The AiMeRe deliver a draft of recommendations for Design for Environment and standardisation. With respect to future aircraft, the recommendations state notably that

- Ideally, there should be less different materials and material combinations
- Less (preferably no) hazardous and toxic materials
- Recycling should be facilitated through better design (**Design for Recycling**)
  - e.g. less use of glue, more easily removable fasteners
- Need to provide more **information for recyclers on aircraft composition**
  - e.g. devise and information system for aircraft recycling

CS1-EDA - WP 2.1.4 Thermoplast Recycling

Successful production of 3 Rotorcraft door hinges through **compression molding** (Eurocopter part– Demonstrator F1) - **Mechanical performance: 20% lower** compared to parts make of new PEEK/CF chips. (FHNW, Switzerland)

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Sustainable Dismantling and Recycling of Metallic Aerostructures

SENTRY, CS1-EDA (2014-2015; FUNDACION GAIKER, SPAIN)

Applicability of the results and value of the knowledge brought by the project:

- An efficient recycling of high-quality aluminium alloys need to include a **selective separation step** to avoid the mixture with other materials which would decrease the final value

- A **decoating step is recommended** when high quality aluminium alloys are recycled. Although no contamination is observed in the chemical composition of the recovered products, the remelting tests of coated samples at laboratory and bench scales show lower metal yield, higher Li losses and high amount of fumes. At industrial scale, rotary furnace recycling could be an option, however the slags associated with this process should be treated later to recover the metal included in this mixture of fluxes and slags.

- A **remelting process with protective atmosphere** is critical to avoid Li losses. At industrial scale, equivalent conditions should be applied to achieve comparable results.

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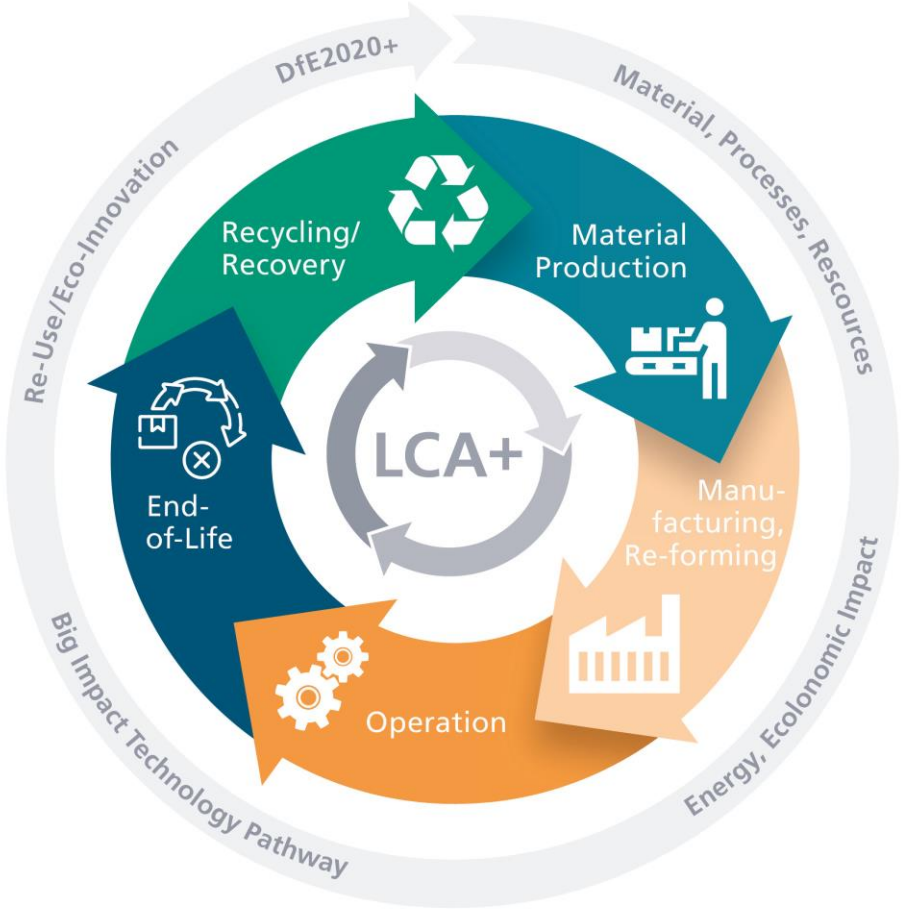
LCA+ APPROACH

What is the main task belonging to the Life Cycle Assessment of Re-Use and End-of-Life of an aircraft?

The main task is to determine the system boundaries used for the LCA. For the first Environmental Product Declaration EPD from Bombardier, the recycling was not taken into account. Only incineration and landfilling. Due the ongoing legislation and to the increasing raw material and energy costs, recycling is becoming more mandatory.

In Clean Sky, LCA is extended towards an LCA+ approach, expanding the system boundaries for LCA towards high re-use and recycling quotes, taken into account as well the production waste and the re-use of expired material (→ low buy to fly ratio). The **boundaries are expanded to produce primary and secondary demonstrators** with recycling material, being able to replace a demonstrator made from new or virgin material. Avoiding the use of “credits” in the final LCA comparison.



Source: Fraunhofer 2022

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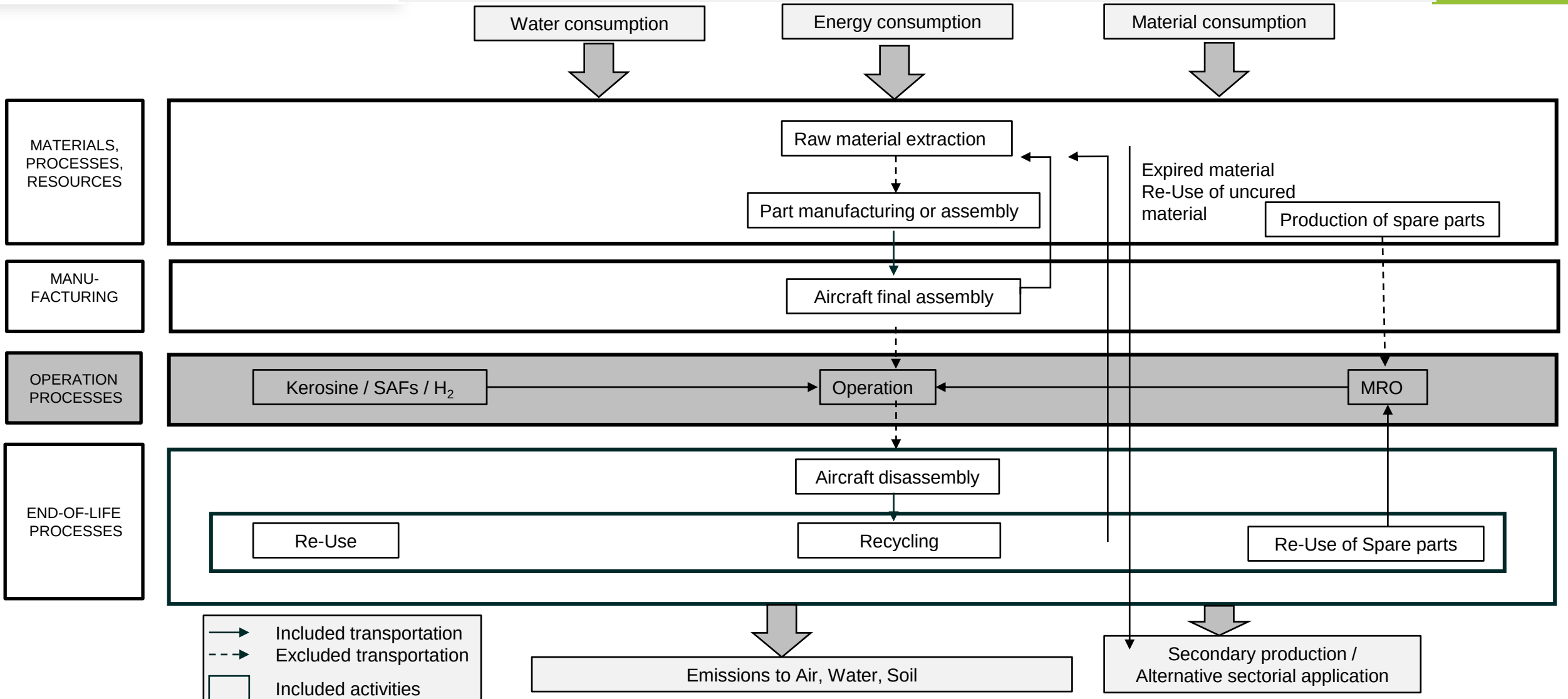
AIRCRAFT LCA+ SYSTEM BOUNDARIES



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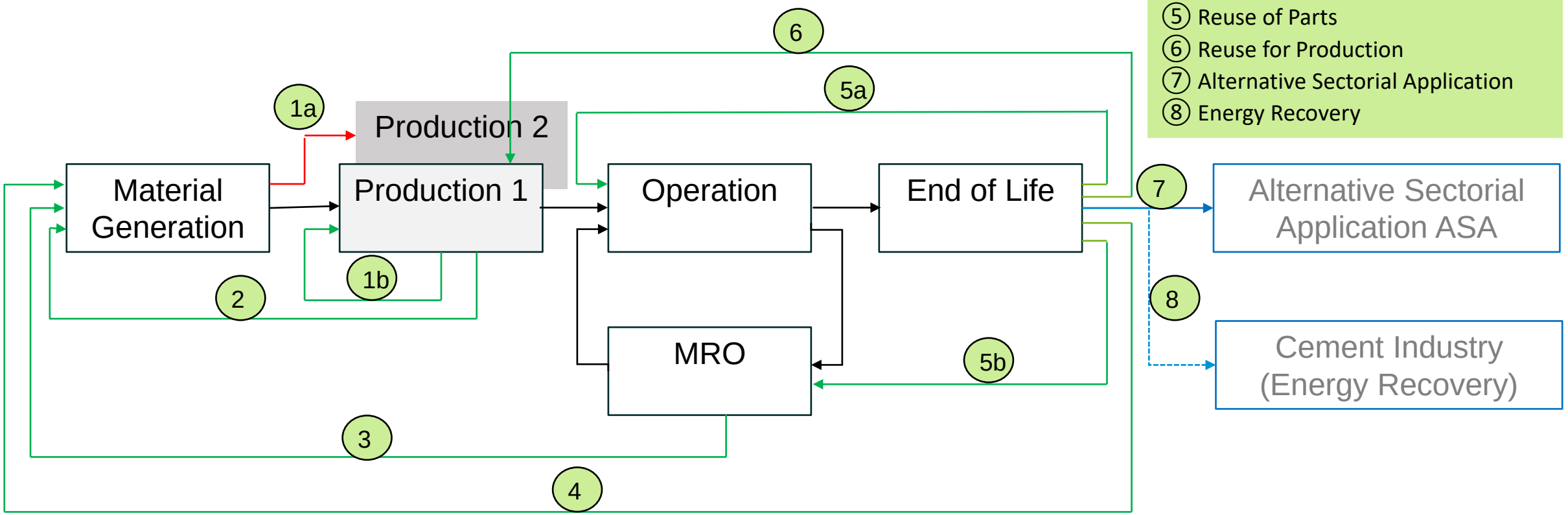
CLEAN SKY 2
CENTRAL COOPERATION RECYCLING

For Green Aviation, a cascade have to be developed to use of recycled materials to fit to production waste and EoL needs – Therefore primary and secondary recycling routes have to be investigated

① Production Waste (expired, inline)
② Production Waste (offline)
③ MRO Waste
④ EoL Waste
⑤ Reuse of Parts
⑥ Reuse for Production
⑦ Alternative Sectorial Application
⑧ Energy Recovery



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CLEAN SKY 2 ACTIVITIES LINKED TO THE CENTRAL COOPERATION RECYCLING

Technology Stream	Activity	①a Production Waste (expired)	①b Production Waste (inline)	② Production Waste (offline)	③ MRO Waste	④ EoL Waste	⑤ Reuse of Parts	⑥ Reuse for Production	⑦ Alternative Sectorial Application	⑧ Energy Recovery
Thermosets	ENG WP9.2	1	1					1		
Thermosets	MANIFICA (CfP)	1	1					1		
Thermosets	HELACS (CfP)					1	1	1		
Thermoplastics	ECOCLIP (CfP)							1		
Thermosets	AIR C-2.1.4 Geopolymer								1	1
Metals	Powder Recycling (AM)			1						
Biomaterials/ Cabin Waste	AIR C-2.1.4 /DIGESTAIR								1	
Biomaterials	AIR C-2.1.4 Biomaterials					1		1		
Biomaterials	ELIOT (CfP)					1				
Thermoplastics	SPARTA (CfP)					1		1		
Metals	ReINTEGRA (CfP)			1		1		1		
Paintings, Coatings	VULCAN (CfP)				1					
Thermoplastics	RESET (CfP)					1		1		
Thermosets	CUSTOMISIZE (CfP)					1		1	1	
Thermoplastics	AIR C-2.1.4 PEKK Waste			1						
Thermosets	AIR C-2.1.4 PUR CFRP Recycling			1		1		1		
Thermosets	AIR C-2.1.4 Plastic Metal Separation			1		1				
Thermosets	AIR C-2.1.4 Reuse of Polyols					1		1		
Thermosets	RECYCOMP		1	1				1		
Thermoplastics	AIR C-2.3.3 Window Frame Demonstrator			1		1		1		
...	...									
...	...									
...	...									
	Total amount of activities	2	3	7	1	11	1	13	3	1

① Production Waste (expired, inline)
② Production Waste (offline)
③ MRO Waste
④ EoL Waste
⑤ Reuse of Parts
⑥ Reuse for Production
⑦ Alternative Sectorial Application
⑧ Energy Recovery

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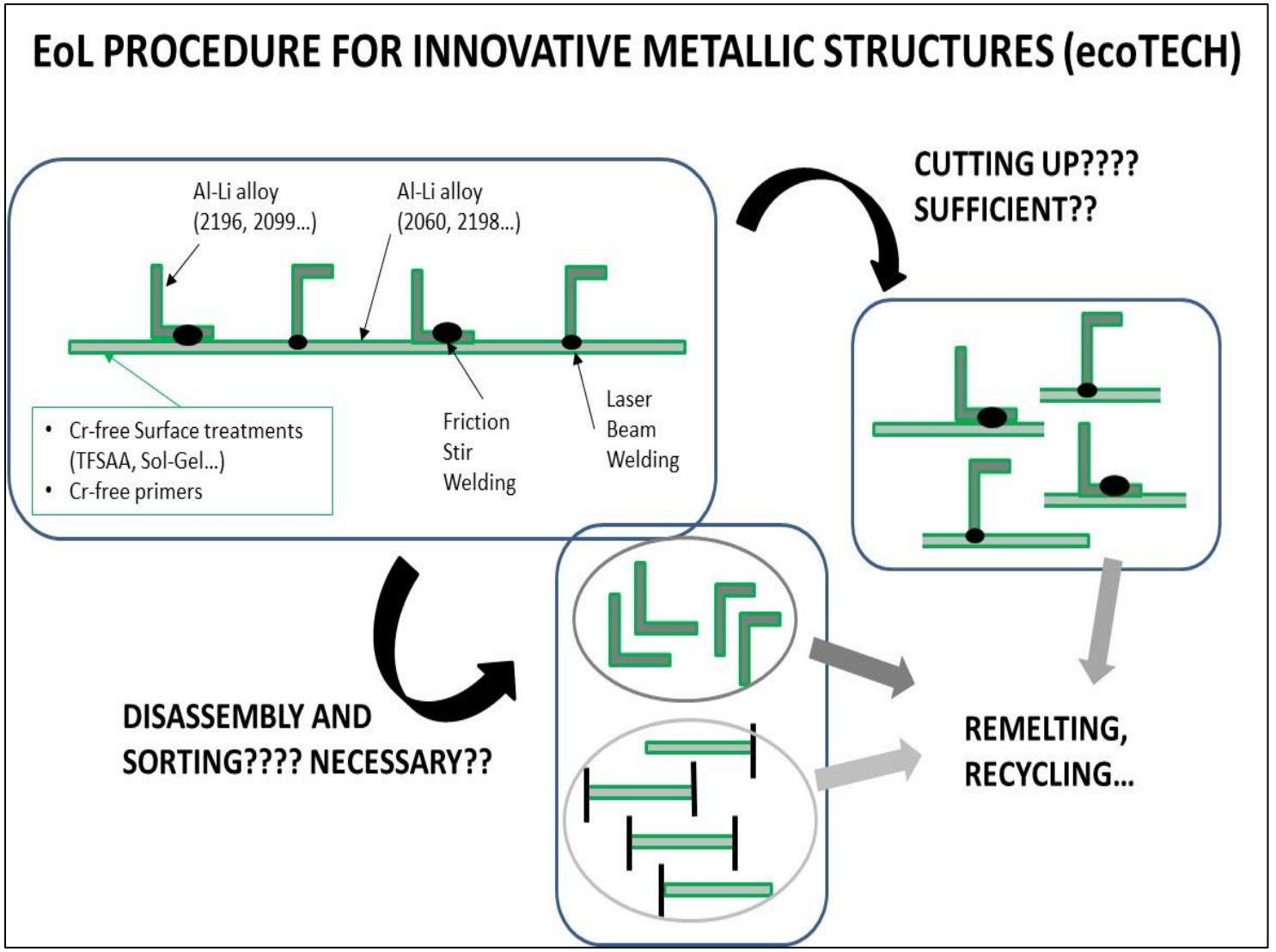
METALL RECYCLING

ReINTEGRA

Topic-Leader: Aero Magnesium, IL
CfP-Leader: Fundacion Azterlan, ES

Goal:
Innovative End of Life procedures for recycling integral Al-Li Alloy Aerostructures

Technologies:
Laser Beam Welding and Friction Stir Welding
Cr-free Surface Treatments
Different cutting strategies for full separation of 3rd generation Al-Li-Alloys
Determine the influence on recyclability
De-coating methods to eliminate primer/topcoats



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EXAMPLES COATINGS

Chemical Stripping (ref. technology)

Topic-Leader: HAI, GR

Hellenic Aerospace Industry

Goal:

Chemical stripping process able to remove all the surface treatments and coatings above the substrate

Reference Technologies:

- Effective and quick technology for total removal of all surface treatments and coatings
- Typical stripping compounds are sprayable liquids containing several chemicals that negatively impact the health of employees and the quality of ground water
- Water waste
- Several rinsing steps are required
- The used chemicals are not always REACH compliant

VULCAN - Selective Paint Stripping

Topic-Leader: HAI, GR

Associated topic leader: AKZO, NL

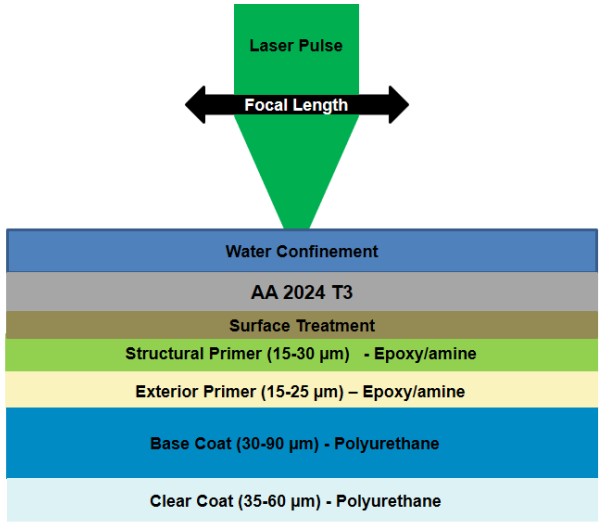
CfP-Leader: CNRS, FR

Hellenic Aerospace Industry

Goal:

Industrial laser stripping process able to selectively remove layer by layer the top coat of an aircraft paint

New Technologies:



Laser Shock Stripping, Reduction of hazardous wastes, no water consumption, limited worker exposure to hazardous substances, Universal solution for metallic and composites Selective for thin layers with low impact

Picture Source: AKZO

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EXAMPLES THERMOSET RECYCLING

HELACS

Topic-Leader: Airbus
CfP-Leader: AITIIP, ES

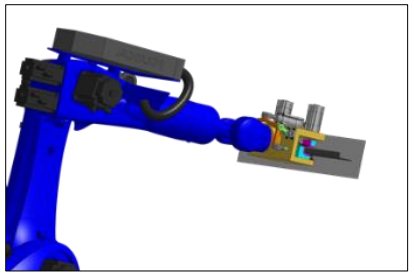
Goal:

Demonstrate a comprehensive dismantling methodology to enable the classification, recycling and reuse of large components of composite materials from EoL

Technologies:

Recovery routes maximizing the retention of value of the different aircraft components; enable European aeronautical industry to lead the dismantling processes e.g. by Water Jet Cutting / Resistance Welding;

Extrapolation to other sectors that generate composite material waste



MANIFICA

Topic-Leader: Fraunhofer; DE
CfP-Leader: University of Bordeaux, FR

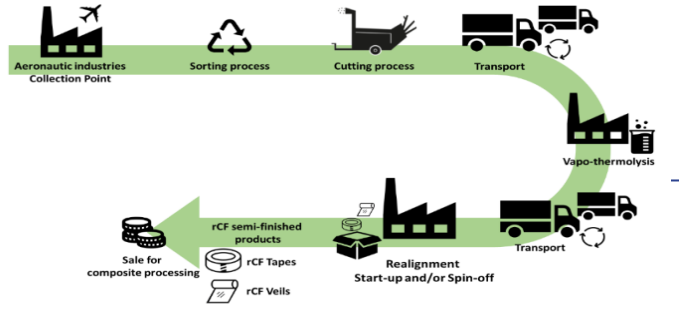
Goal:

Set-Up and testing of full recycling chain for carbon fibre containing wastes considering all aspects from logistics, recycling and manufacturing of high-quality rCF semi-finished products in an industrial scale.

Technologies:

Collection and segregation system for CFRP waste
Realignment technology for rCF semi-finished products
Re-Use analysis for shelf-life extension of prepregs
Manufacturing of different rCF semi-finished products
Demonstrator parts out of rCF semi-finished products

Picture Source:
MANIFICA Recycling



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EXAMPLES THERMOSET RECYCLING

CUSTOMISIZE

Topic-Leader: Fraunhofer; DE

CfP-Leader: LEITAT, ES

Goal:

New ways to recycle carbon fibres by sizing them to improve mechanical properties of composite materials

Technologies:

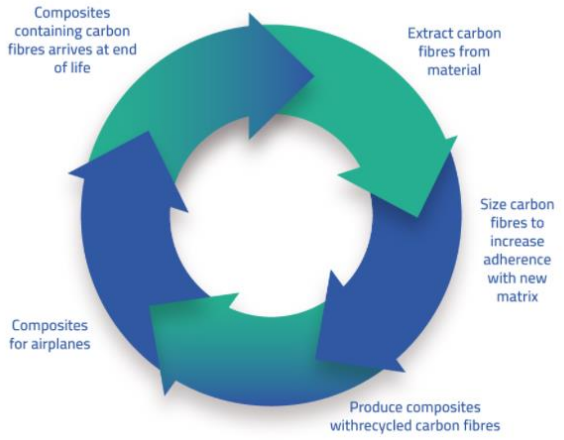
Sizing material inventory

Steam water thermolysis

Thermolysis (FhG)

Fibre sizing and characterisation

Application for composite parts



RECYCOMP

Topic-Leader: LEONARDO, IT

CfP-Leader: Fundación Tekniker, ES

Goal:

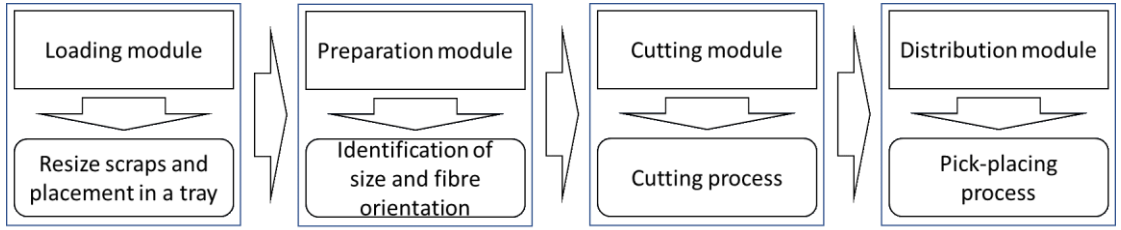
Developing a machine for recovery and recycling of pre-impregnated carbon fibre uncured scraps.

Technologies:

Automated identification the scraps' area and fibre orientation

Cut the scrap into rectangular chips

Placing on a new backing material for subsequent use.



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EXAMPLES POLYURETHANE RECYCLING

Re-Use of Polyols

Topic-Leader: Fraunhofer, DE

Goal:

To Re-Use recycled Polyols from PUR foams and from rigid CF-PUR structures

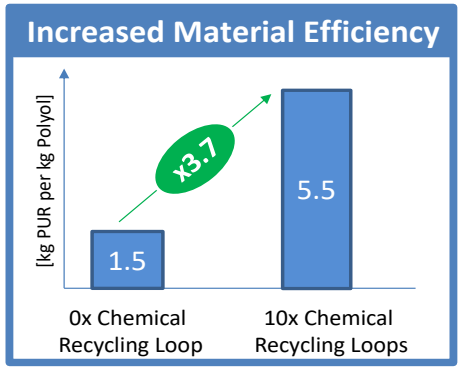
Extrapolation on aircraft fleet level

Technologies:

Solvolysis

PUR Foaming

Picture Source: Fraunhofer ICT



Dismantling Concepts

Topic-Leader: Fraunhofer, DE

Goal:

To dismantle hybrid seating structures with rigid CF-PUR, PUR Foams and metal inserts

Recycling of hybrid manufactured parts

Technologies:

Shredding

Metal-Plastic-Separation

Picture Source: CfP HAIRD, LEITAT

Picture Source: Fraunhofer ICT

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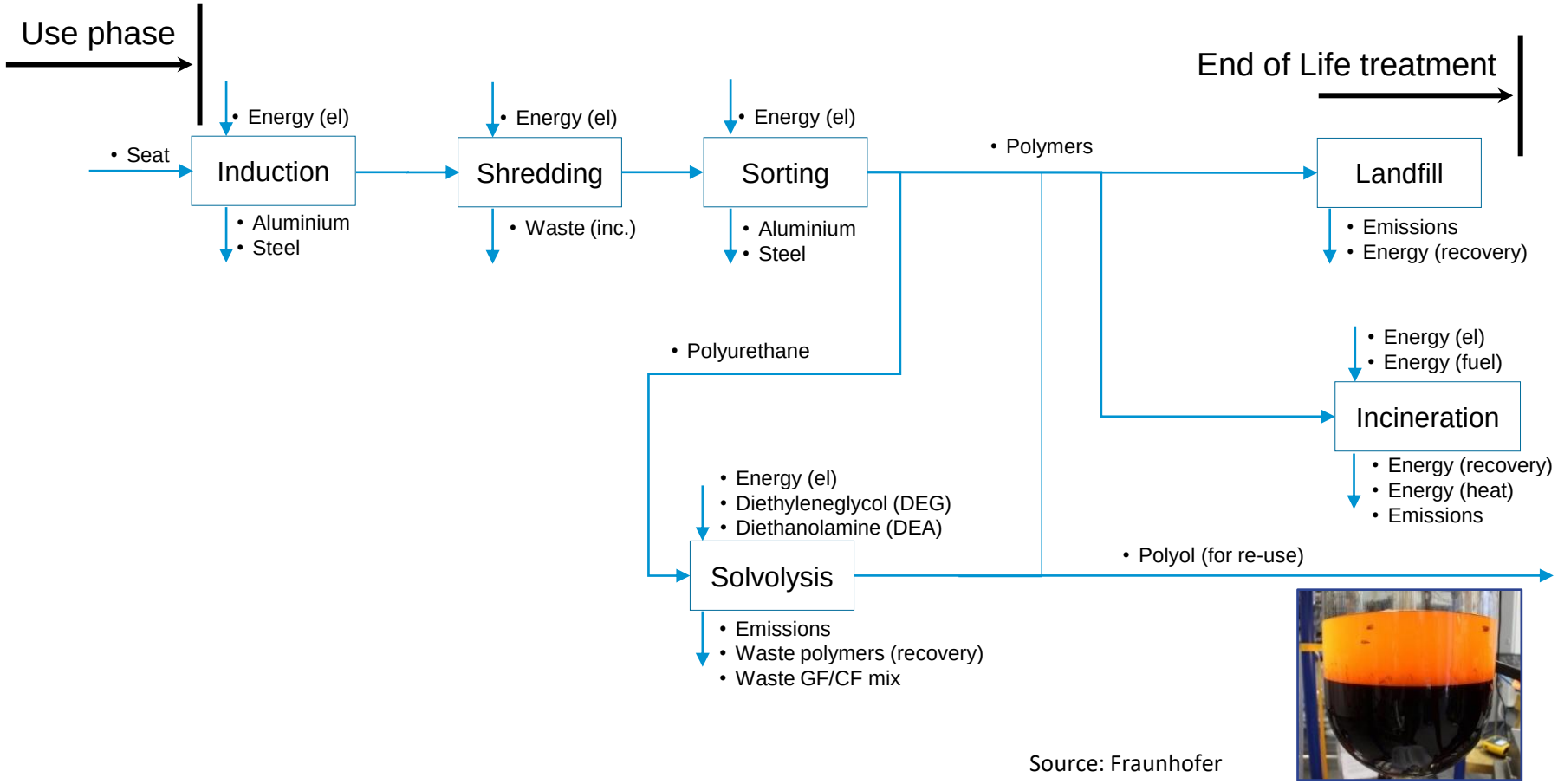
PROCESS FLOW PUR-CFRP SOLVOLYSIS

All ecoDESIGN activities linked to ECO TA and to Flagship Demonstrators will deliver process flow charts for the recycling process to develop a complete recycling concept.

The complete re-cycling concept have to be comparable to the alternative complete concepts.



Source: Fraunhofer

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EXAMPLES BIOMATERIAL RECYCLING

DIGESTAIR

Topic-Leader: Fraunhofer, DE
CfP-Leader: Asociacion Centro Tecnologico Ceit, ES

Goal:
Improve waste management on board by taking advantage of the anaerobic digestion (AD) process

Technologies:
Two stage anaerobic digestion process
Alternative process with membrane filtration
Energy Recovery
C[illegible]

Picture Source: Fraunhofer IBP

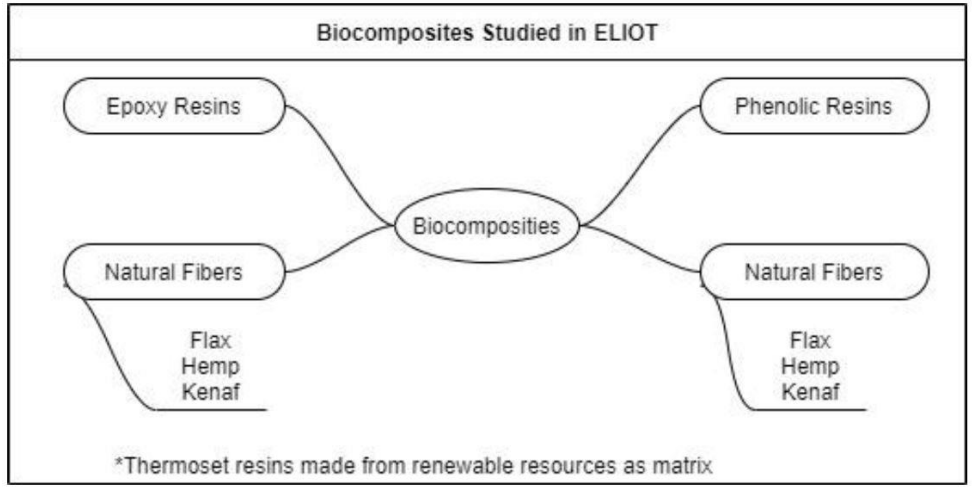
Picture Source: CfP DIGESTAIR, ACTC

ELIOT

Topic-Leader: INVENT, DE
CfP-Leader: AIMPLAS, ES

Goal:
Environmental sustainability in aeronautics by using new bio-composite recycling methods

Technologies:
Mechanical, thermal, chemical and biological recycling
Recycling of bio-composites



Source: AIMPLAS

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EXAMPLES THERMOPLAST RECYCLING

ecoTECH

Topic-Leader: NLR, NL

Goal:

Recycling of PEKK plates (NLR)

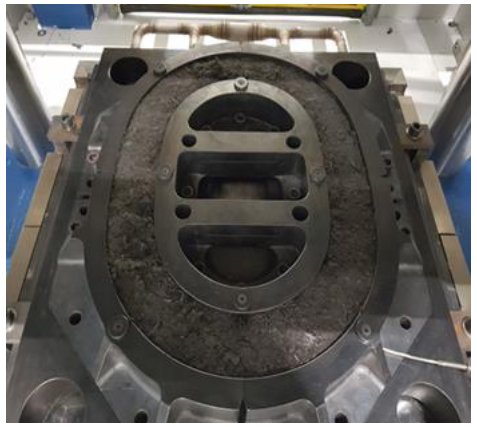
Waste stream analysis during PEKK plate production (FhG)

Technologies:

Mechanical scrapping

Electrodynamic fragmentation

Compression moulding of window frames



Compression moulding of window frame

SPARTA

Topic-Leader: NLR; NL

CfP-Leader: AIMPLAS, ES

Goal:

New method of recycling and reprocessing composite thermoplastic materials

Technologies:

Innovative mechanical scrapping process using simulation and experimentation (slicing)

Automatic deposition and compression moulding

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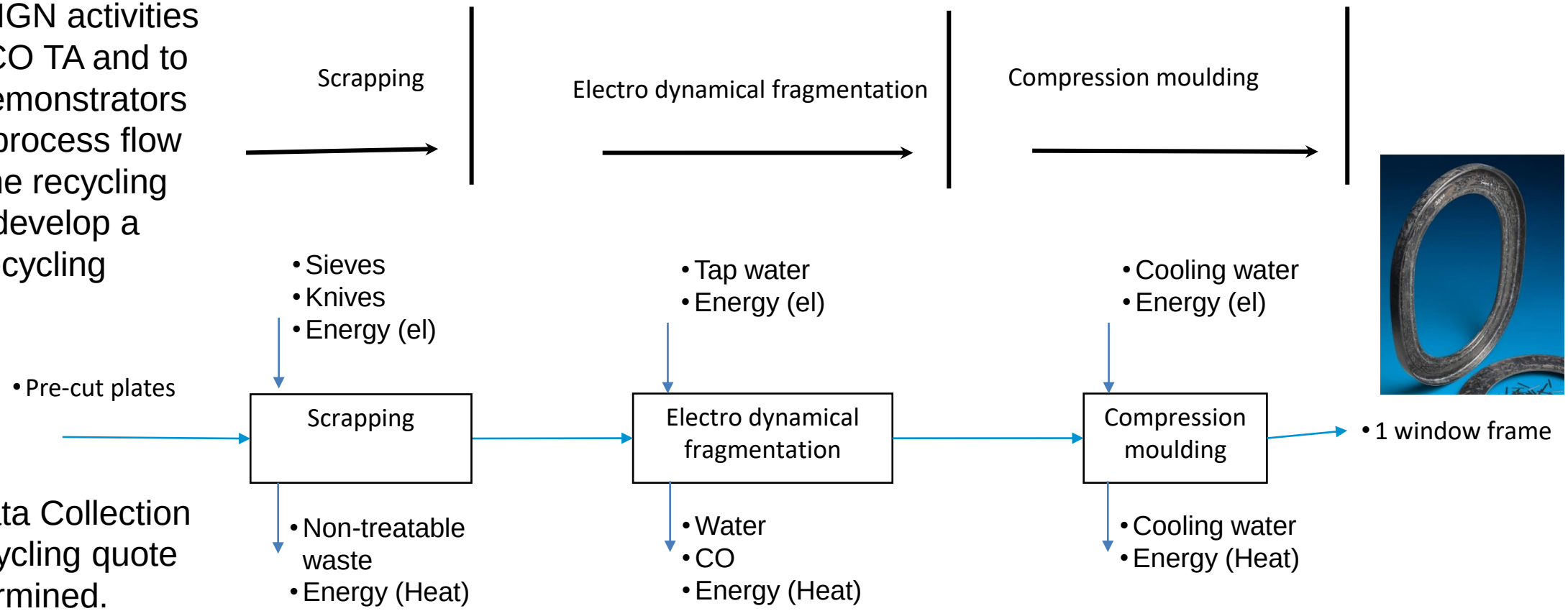
PROCESS FLOW PEKK RECYCLING

All ecoDESIGN activities linked to ECO TA and to Flagship Demonstrators will deliver process flow charts for the recycling process to develop a complete recycling concept.

With the Data Collection the real recycling quote will be determined.



Source: NLR

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EXAMPLES THERMOPLAST RECYCLING

ECO-CLIP

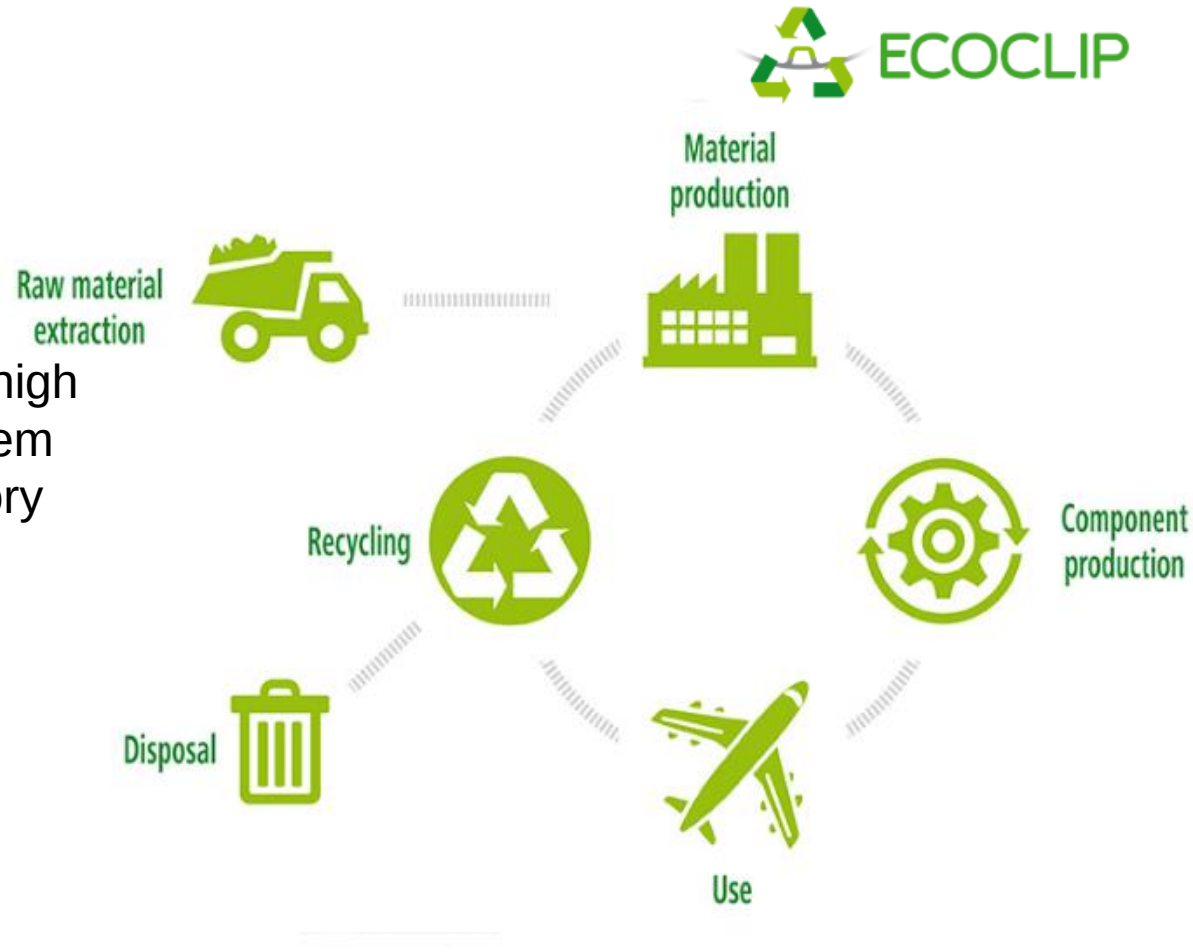
Topic-Leader: GKN-FOKKER
CfP-Leader: AIMEN, ES

Goal:

ECO-CLIP project aims to demonstrate the technical, environmental and economic feasibility of manufacturing high added-value structural aircraft parts (frame clips and system brackets) using recycled CF/LMPAEK obtained from factory waste

Technologies:

Thermoplastic composites mechanical recycling
Melt extrusion compounding
Injection moulding process
Injection moulding process simulation by FEM
3D printing
Thermoplastic composite welding technologies



Source: ECOCLIP

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CONCLUSION

- The current aircraft recycling business is highly dependent on the value of extracted spare parts and the volatile raw material prices
- Avoidance of production waste is, and will continue to be, a key target
- Production processes have to be optimized and new disruptive ones to be developed
- Implementation of Design for Recycling (DfR) towards Design for Circularity and Design for Environment (DfE)
- A cascade have to be developed to use of recycled materials to fit to production waste and EoL needs – Therefore primary and secondary recycling routes have to be investigated
- ecoDESIGN® assess the best practice in material recycling and recovery
- Smart logistic systems and networks have to be developed for the reduction of recycling costs and development of new business models
- The need for a clear regulation causes a direct dependency of the recycling rate and on the market prices

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CLASSIFICATION OF CIRCULARITY METRICS

New Circularity metrics are being developed, but they often present contradictions.

Non of them are addressing the CE concept in full, **potentially leading to undesirable burden shifting** from reduced material consumption to increased environmental, economic or social impacts.

Source: Corona et. al. 2019
https://doi.org/10.1016/j.resconrec.2019.104498

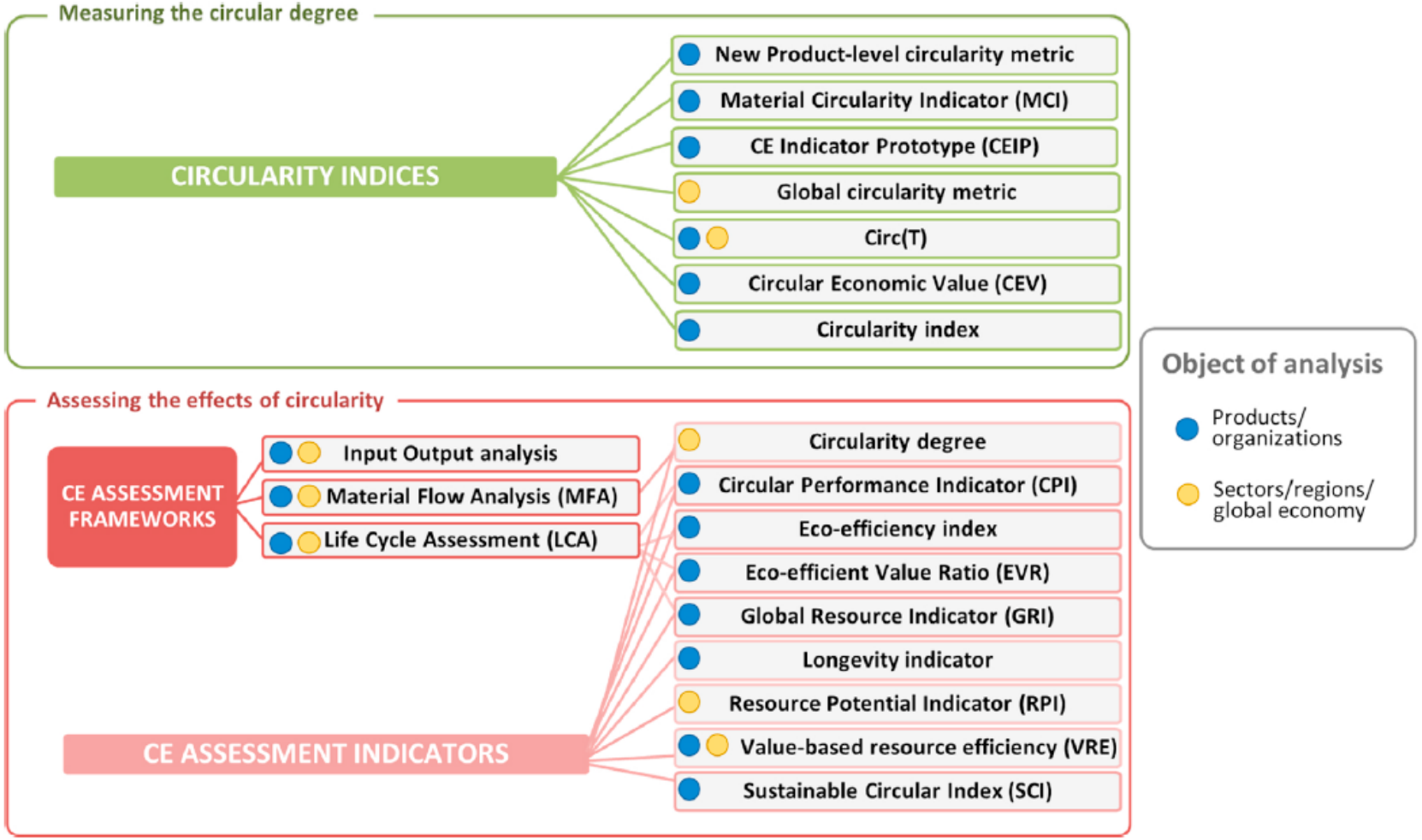

Fig. 1. Classification of reviewed circularity metrics. *Additional indicators applied within the assessment frameworks are described in detail in Table 2.

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BREAKING NEWS – VDI 7/10/2022

ZKZ 06867 PVSt+2 DPAG Entg. bez.
Herrn Dr.-Ing.
Thomas Reichert VDI
Joseph-von-Fraunhofer-Str. 7
76327 Pfinztal

PSI Software für Versorger und Industrie www.psi.de

VDI nachrichten

PSI Deutscher Logistik-Kongress Berlin, 19.–21.10.2022

7. Oktober 2022 · Nr. 20 TECHNIK WIRTSCHAFT GESELLSCHAFT Einzelpreis 4,40 Euro

Den Kreislauf schließen

FOKUS: Industrie, Forschung und Politik arbeiten daran, dass Kunststoffe vollständig recycelbar werden. Doch noch ist eine echte Kreislaufwirtschaft hier nicht in Sicht.

VON BETTINA RECKTER

Der Staatengemeinschaft ist es ernst: Die Umweltversammlung der Vereinten Nationen hatte im März ein rechtlich bindendes Abkommen im Kampf gegen Plastikmüll verabschiedet. Nun müssen Forschungsinstitute und Unternehmen liefern, um die Kreisläufe wirklich zu schließen. Für die kunststoffverarbeitenden Industrie wird dies auch ein großes Thema auf der Messe K vom 19. bis 26. Oktober in Düsseldorf sein.

Doch trotz politisch geforderter Quoten gestalten sich Rückgewinnung und erneuter Einsatz von Kunststoffen für die Hersteller noch ziemlich schwierig. Zu groß sind die Qualitätseinbußen etwa beim mechanischen Recycling, auch wenn sich sogar Verbundwerkstoffe immer besser trennen lassen.

Derweil nimmt das chemische Recycling allmählich Fahrt auf. Einer der Vorreiter, die BASF in Ludwigshafen, hat gerade mit der Arcus Greencycling Technologies GmbH die Abnahme von Pyrolyseöl aus gemischten Kunststoffabfällen vereinbart. Eine Demonstrationsanlage in Frankfurt, die erste dieser Art im kommerziellen Maßstab, soll bis zu 100 000 t Pyrolyseöl pro Jahr liefern. Daraus will BASF Produkte mit exakt den gleichen Eigenschaften anbieten wie solche, die auf Erdöl basieren. 20

Feintuning fürs chemische Recycling: Die Erzeugung von Pyrolyseöl aus gemischten Kunststoffen als Ersatz für Rohölprodukte verlässt allmählich den Labormaßstab. Foto: BASF SE

Trucks im Elektrofieber

NUTZFAHRZEUGE: Wie brummt es sich in Zukunft möglichst ganz ohne Treibhausemissionen? Die Dekarbonisierung der Lkw-Flotten weltweit ist das wohl ambitionierteste Vorhaben einer ganzen Industrie, die sich auf der IAA Transportation in Hannover traf. Die Antwort: große Autos, große Akkus – und ein bisschen Brennstoffzellen. Megawatt-Charging ist dabei der Heilige Gral aller Antriebe. Die Branche dreht erkennbar auf bei der Transformation und sie will Tempo aufnehmen. 8

ZITAT

„Wir wollen gerne in Europa produzieren, aber im Gegensatz zu anderen Märkten gibt es keinen Vorteil."

Karsten Brüggemann, Bereichsleiter Zentraleuropa bei Nordex Energy SE, zur Lage der europäischen Windindustrie 12

Ingenieure mit dem Willen zum Wandel gesucht

KARRIERE SPEZIAL: Die Mobilität der Zukunft hat nicht mehr viel mit dem Heute zu tun, mit maroden Straßen und Schienen und der Übermacht von Verbrennermotoren. Gute Ideen gibt es, der Fachkräftemangel setzt ihnen aber personelle Grenzen. Ingenieurinnen und Ingenieure sehen sich einem schier grenzenlosen Betätigungsfeld gegenüber. 26

Das Carsharing ist nur ein Beispiel für den massiven Wandel der Mobilität. Foto: imago images/Westend61

Closing the Loop
Industry and Policy working on plastic recycling. Real Circular Economy is not in sight

Chemical Recycling is advancing:
Pyrolysis Oil from mixed plastic waste → 100 000 t Polystyrene per year with similar properties as virgin material

→There is still a lot to do for Circularity in Aviation

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THANK YOU FOR YOUR ATTENTION

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