LIFE CYCLE ASSESSMENT OF ECOLOGICAL IMPROVED COMPOSITES FOR AVIATION – A REVIEW

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Jens Bachmann (DLR)

Carme Hidalgo (LEITAT)

Stéphanie Bricout (AGI)

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Content

- Background
- LCA methodology
- Selected results of literature survey
- Conclusions & Outlook

Background

Growing market for aviation [1]:

- Air traffic more than doubles in the next 20 years
- 4.5 % growth of passenger traffic p.a. until 2035
- 32.425 passenger aircraft required over the next 20 years

Environmental challenges [2]:

- Climate change
- Loss of biosphere integrity (biodiversity loss and extinctions)
- Nitrogen and phosphorus flows to the biosphere and oceans
- Landsystem change
- …

[1] Airbus Global Market Forecast 2016-2035

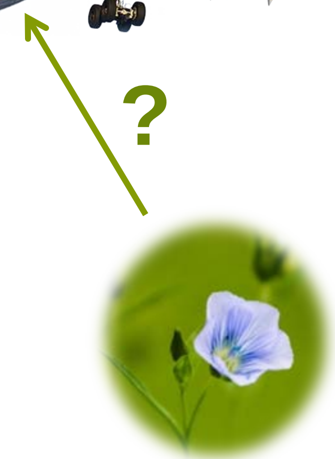
[2] Stockholm Resilience Institute: The nine planetary boundaries

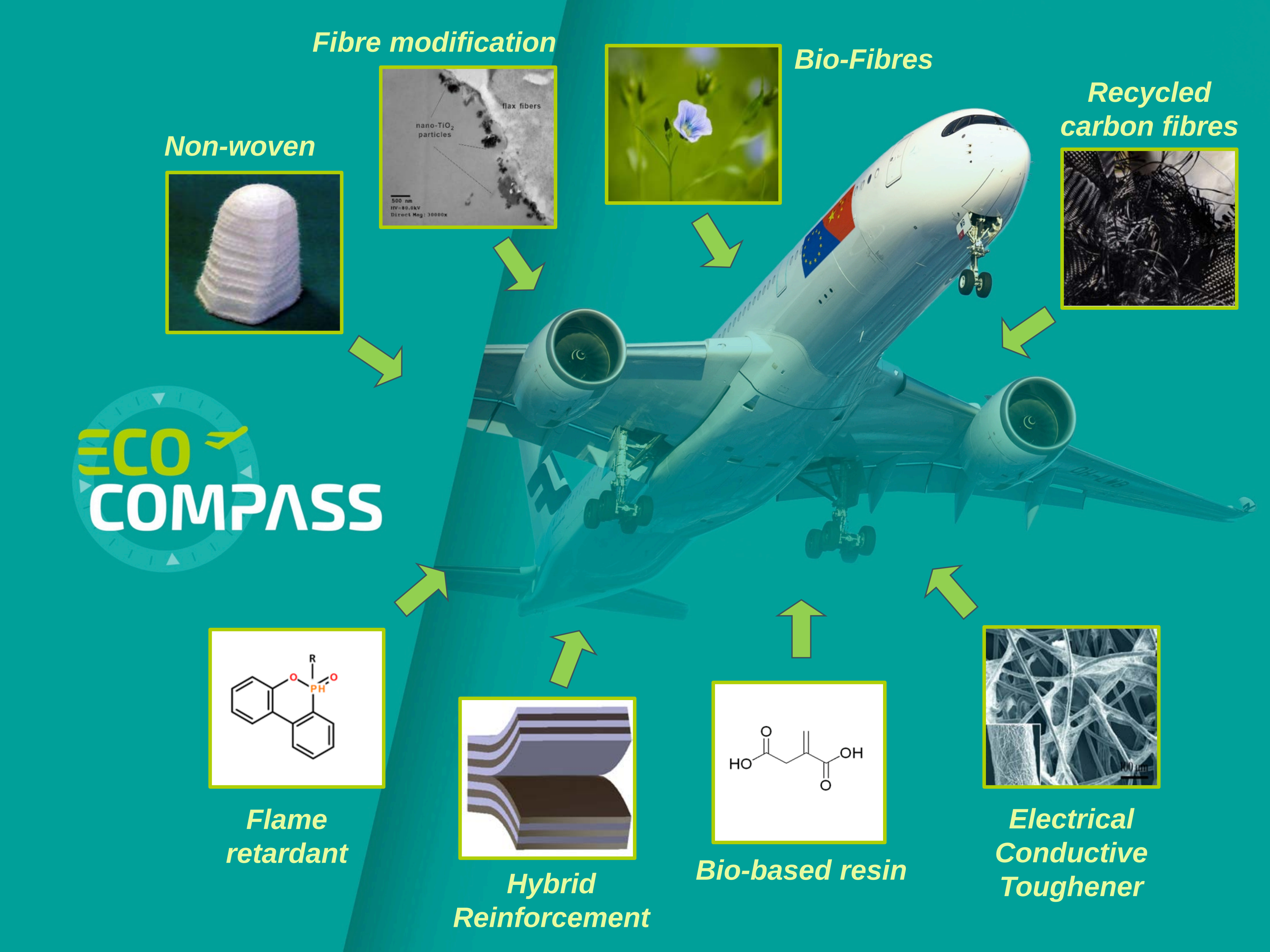
Measures with potential to reduce aviations environmental impact

- Aircraft configuration
- Propulsion / alternative fuels
- Aerodynamics
- Trajectory / flight path
- Energy management
- …
- **Lightweight design**
  - **Fibre Reinforced Composites**
    - **CFRP, GFRP, GLARE, …**

→ All synthetic / man-made materials

→ Bio-fibres?
→ Bio-resins?
→ Recycled fibres?





Fibre modification
flax fibers
nano-TiO2 particles
500 nm
Bio-Fibres
Recycled carbon fibres
Non-woven
ECO COMPASS
Flame retardant
Hybrid Reinforcement
Bio-based resin
Electrical Conductive Toughener

How to assess potential environmental impacts?

- Life Cycle Assessment (LCA)
  - **A method of analysing and quantifying the potential environmental impact of a product, process or activity.**
- ISO 14040 & 14044
- Cradle-to-grave approach:
  - **Extraction of raw materials → pre-treatment → production of a good → distribution → use-phase → waste management**
- (Cradle-to-gate, gate-to-gate)

- LCA supports
  - Product development and improvement
  - Strategic planning / decision making
  - Public policy making
  - Marketing („Greening“ vs. Facts)

LCA framework: Four Phases

1. Goal & Scope
Definition of the product system in terms of the system boundaries and a functional unit (reference unit)

2. Inventory Analysis (LCI)
Data collection and calculation procedures to quantify the relevant inputs and outputs of the product system

3. Impact Assessment (LCIA)
Connecting inventory data with specific environmental impact categories and the respective category indicators

4. Interpretation
Compilation of findings from both LCI and LCIA to provide conclusions and recommendations

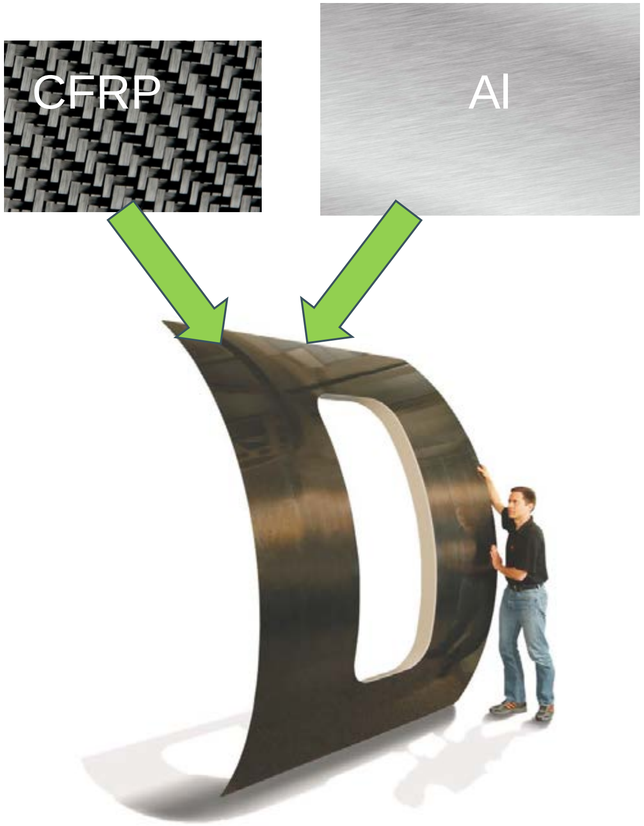
[EN ISO 14040]

LCA Phases:
Goal & Scope

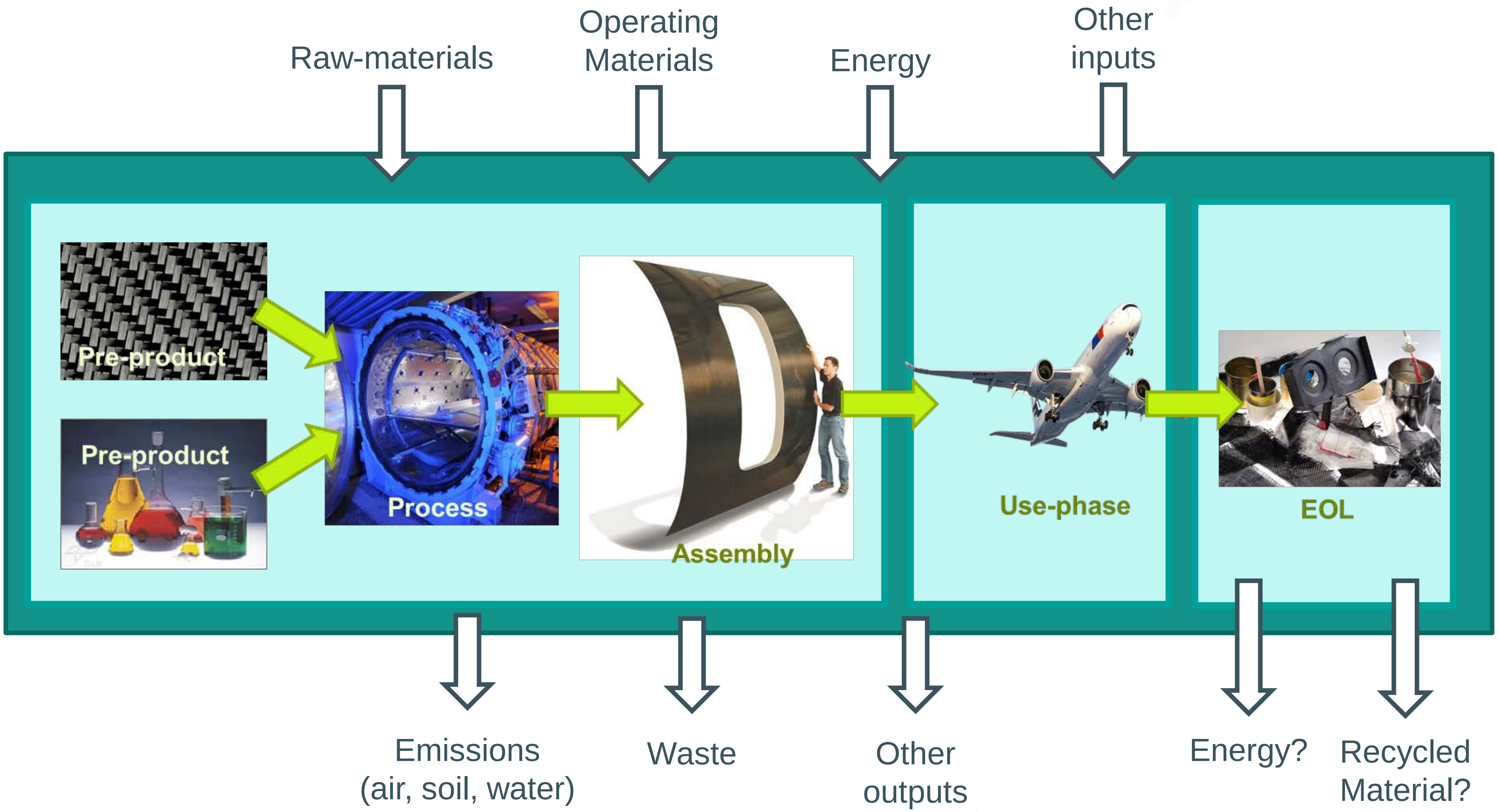
- Goal and Scope definition
  - Reasons for LCA?
  - Target audience?
  - System description and assumptions

- Functional Unit (FU)
  - Reference to relate inputs and outputs
    - **Poor example: Compare on volume/mass basis**
    - **Better example: Functional equivalence!**

- System boundaries
  - Technical system and nature
  - Geographical area (energy mix)
  - Exclusions / Cut-off threshold



LCA Phases:
Inventory Analysis (LCI)



LCA Phases:
Impact Assessment (LCIA)

Classification
e.g. CO_2, N_2O, CH_4 → GHG

Characterisation
e.g. GWP100
CO_2 = 1, CH_4 = 23 kg CO_{2eq}, 1 kg of N_2O = 298 kg of CO_{2eq}

Normalization
e.g. greenhouse gas emissions EU-28 in 2015:
4.419 Mt CO_{2eq}

Weighting
e.g. aggregation of several normalized environmental impacts

→ **Midpoint**

Fossil depletion, metal depletion, water depletion, natural land transformation, urban land occupation, agricultural land occupation, marine ecotoxicity, freshwater ecotoxicity, terrestrial ecotoxicity, marine eutrophication, freshwater eutrophication, terrestrial acidification, ionising radiation, particulate matter formation, photochemical oxidants, human toxicity, ozone depletion, climate change.

→ **Endpoint**

e.g.
human health, ecosystem quality and resource depletion

Various LCIA -methodologies covering *all* environmental impacts:
e.g. ReCiPe, CML2001, EDIP, EI99, ILCD, TRACI…

SoA materials for composites in aviation (LCA data)

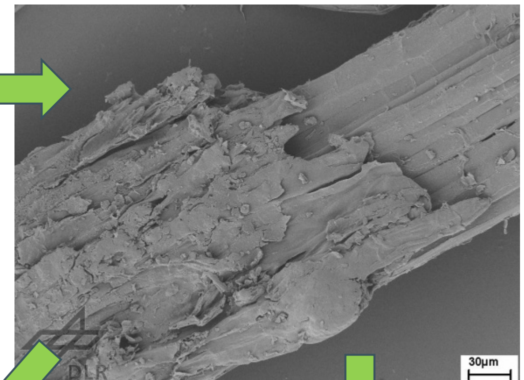
Material	Energy (MJ/kg)	GHG (kg CO_{2eq}/kg)	Source
Epoxy resin	76-80	-	Michaud 2016
	137	8.1	Plastics Europe
	76-137	4.7-8.1	Deng 2014
	76	-	Suzuki 2005
Phenolic resin	-	7.0 (foam)	Densley 2014
	33	-	Suzuki 2005
	102 (incl. FRP manuf.)	5.8	Moliner 2013
Carbon fibres	286 (186-360)	22.4	Michaud 2016
	1 122	53 (std)	Verpoest 2014
	286-704	24.4-31	Deng 2014
	286 (JMCA 2004)	-	Suzuki 2005
	286 (JMCA 2009)	-	Zhang 2009
Glass fibres	45.6	2.5	Michaud 2016
	21.1	-	Dai 2015
	13-32	-	Song 2009
	45	2.6	Deng 2014
	10.3 glass 30 (incl. comp manuf.)	1.6	Moliner 2013
Aramid paper	-	-	none

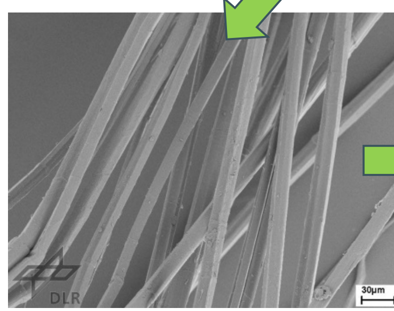
Composites in Aviation (LCA)

- Composites for structural applications are commonly more energy intensive during production phase
- The use-phase is very important for transportation, especially for emissions from energy consumption.
- Composites, if designed optimal, can surpass classic metals during the use-phase because of lighter weight and less fuel consumption.
- **Therefore it is of highest importance to assess the complete life-cycle of an airplane and not only a cradle-to-gate approach**

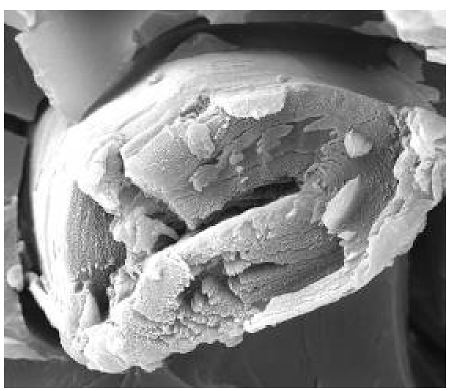
Natural Fibres

Flax (Linum usitatissimum)



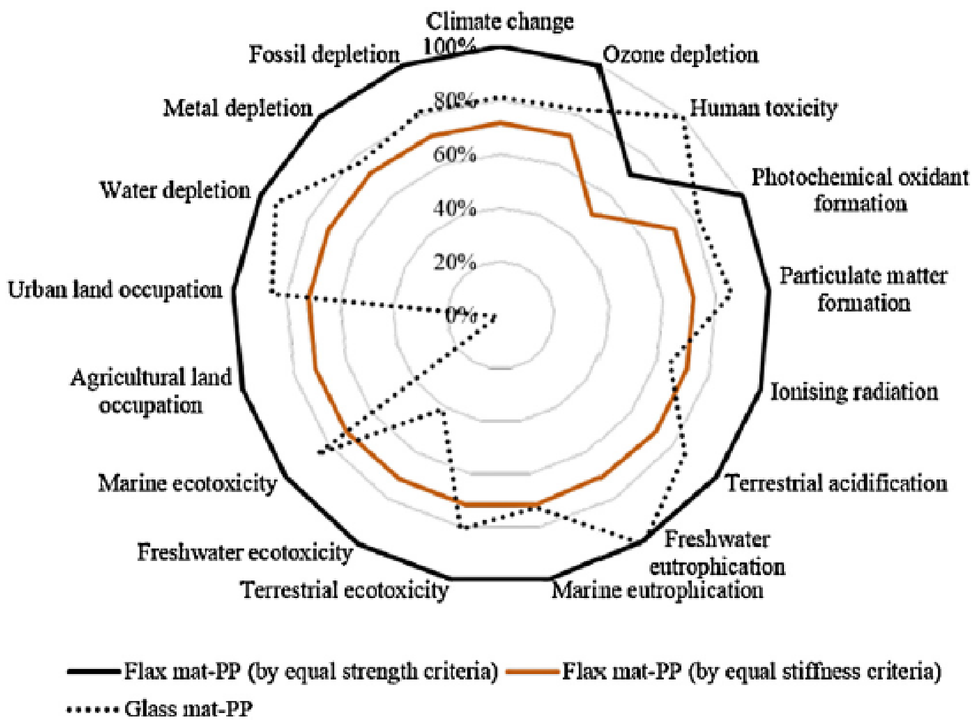


Ramie (Boehmeria nivea)



[Wang et al 2015]

Natural Fibres
LCA example: NFRP vs. GFRP

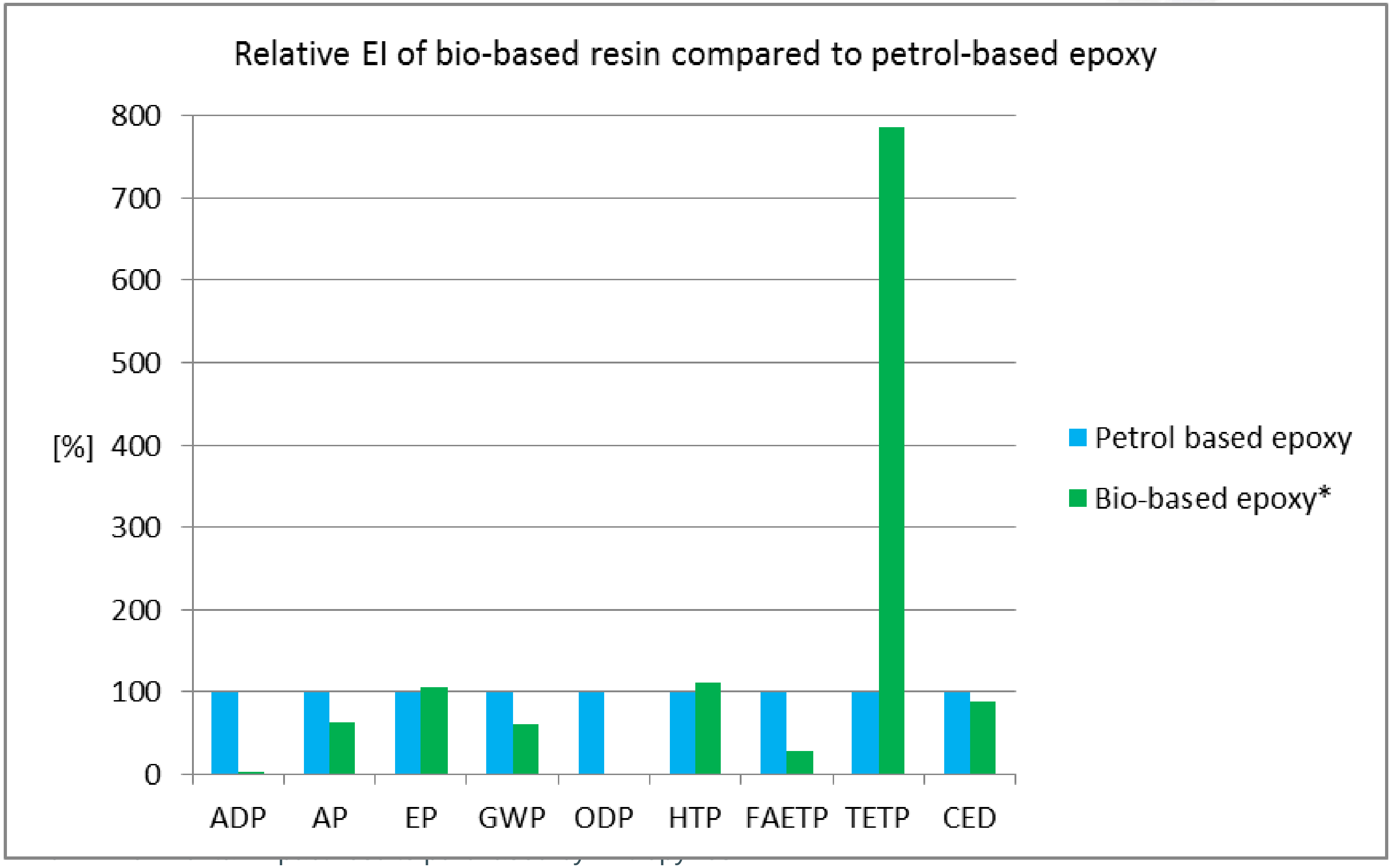


[Duflou JR, et al. Comparative impact assessment for flax fibre versus conventional glass fibre reinforced composites: Are bio-based reinforcement materials the way to go?. CIRP Annals - Manufacturing Technology (2014)]

Bio-resins

Natural rubber
Turpentine oil
Lignin derivatives
Rosin
Brazilian tree
Conifers
Soybean oil
Land plants
Tannins derivatives (gallic acid, catechin, tannic acid)
Barks of trees
Soy beans
Soy Beans
Linseed oil
Cashew nut shells
Cardanol
Lin seeds
ECO COMPASS
Green tea
Canola
Catechin
Canola oil
Karanja tree
Starch
Isosorbide
Karanja oil

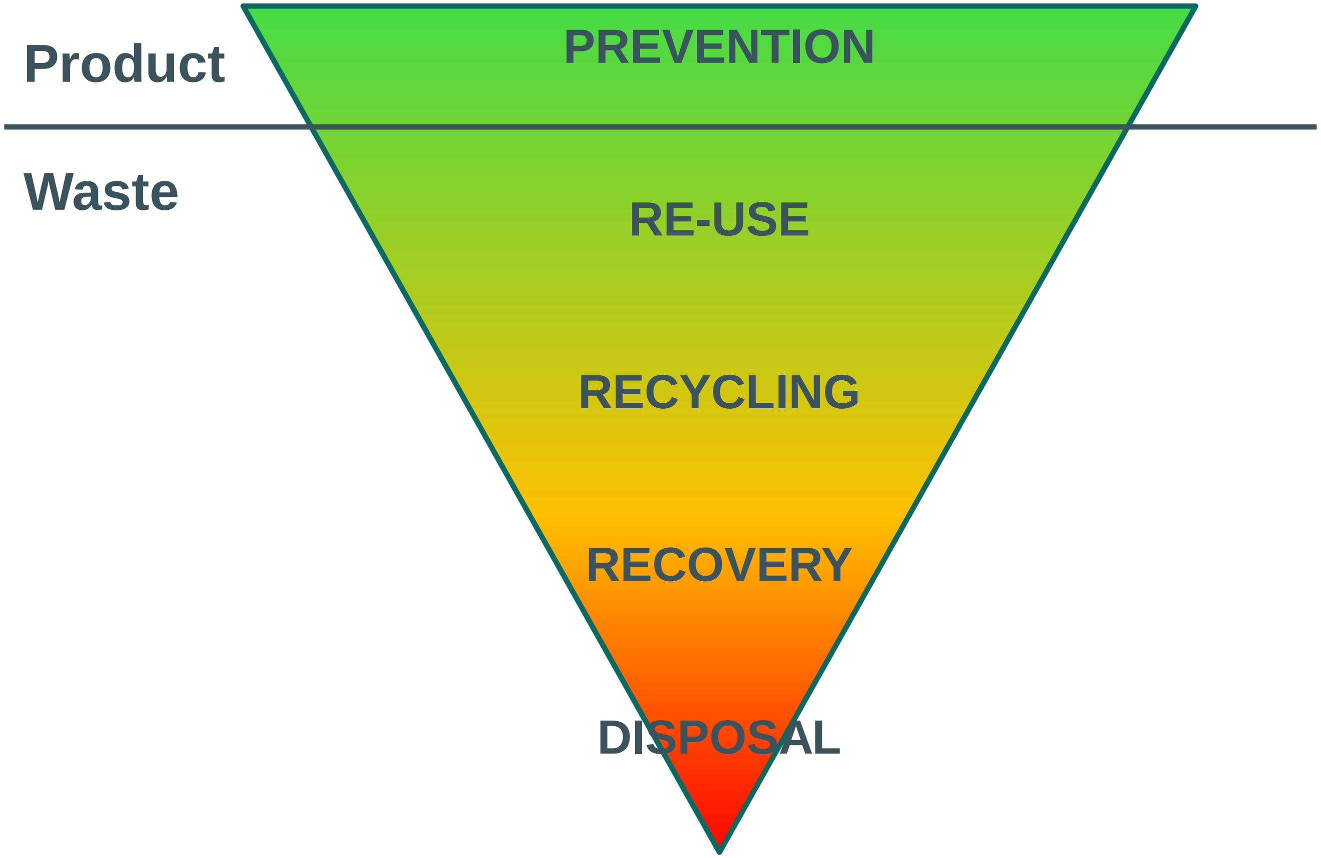
Bio-resins (LCA example)



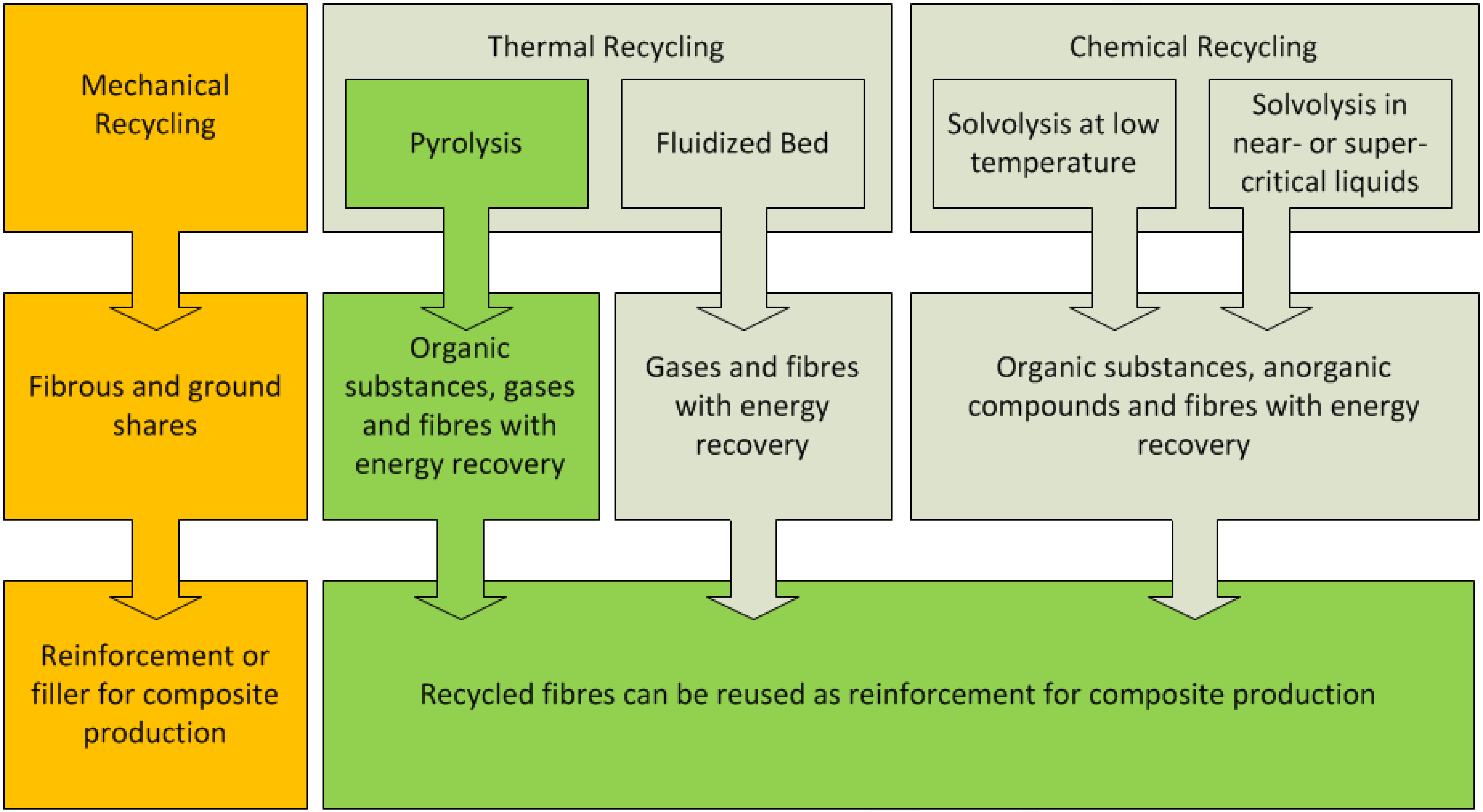
*) 48 % bio-content [Entropy Resins Inc. - Technical Data Sheet – Super Sap™ 100 Epoxy Resin/Super Sap™ 1000 Hardener)

LCA data from [La Rosa A D, Recca G, et al. Bio-based versus traditional polymer composites. A life cycle assessment perspective. Journal of Cleaner Production, 2014, 74: 135-144]

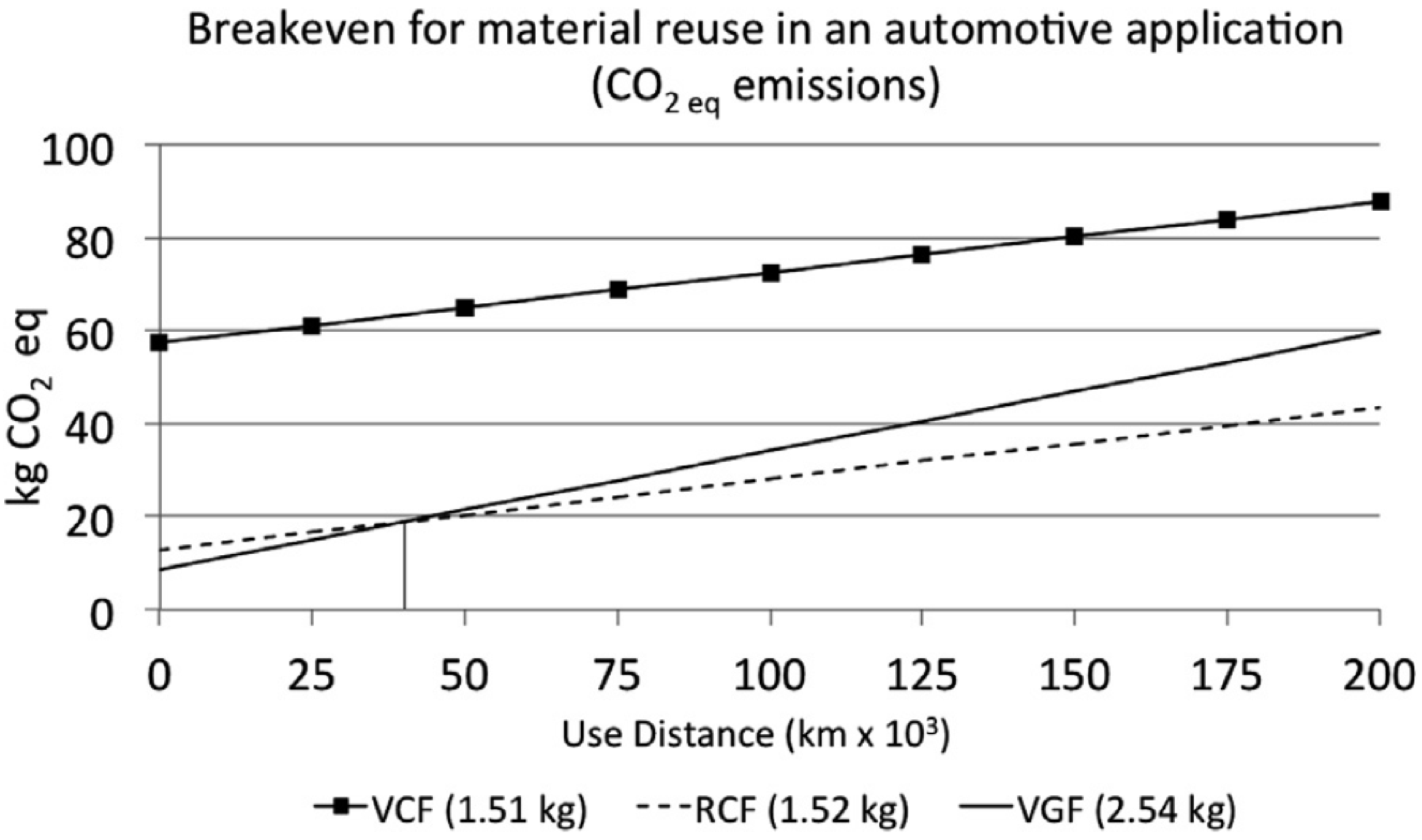
Waste hierarchy



Recycling (Thermoset Composites)



rCF (LCA example)



[Witik R A, Teuscher R, Michaud V. Carbon fibre reinforced composite waste: An environmental assessment of recycling, energy recovery and landfilling. Composites: Part A, 2013, 49: 89-99]

Summary & Outlook

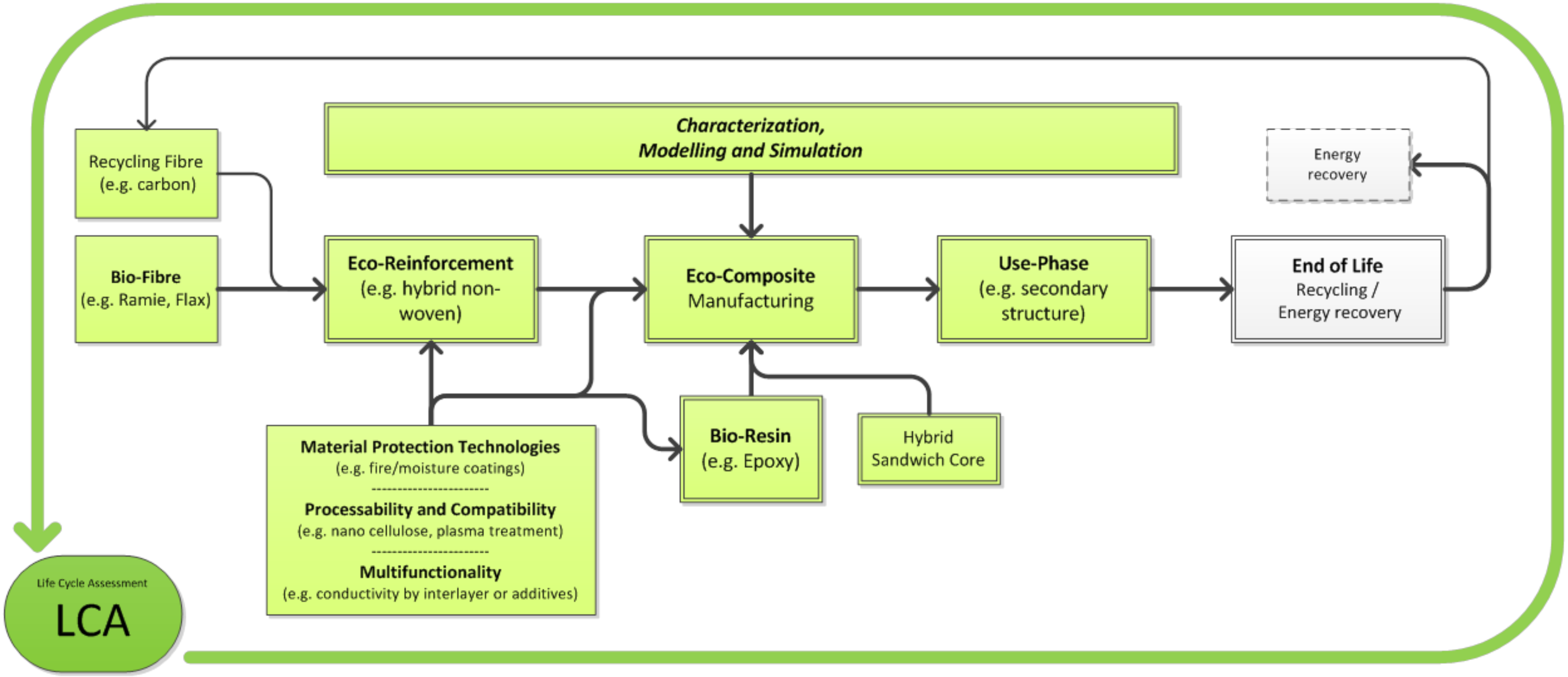
- LCA is an important tool to support the decision making

- Available results show advantages for bio-based composite materials and recycled carbon fibres, but:
  - Data quality is not always clear and a assumptions lead to uncertainties

- Assessment of the complete life cycle, including use-phase
- Consider functional equivalence and material degradation
- Data quality of high importance for correct results

- **In the ECO-COMPASS project, several case-studies on use-cases in Interior and Secondary Structures to compare „eco-materials“ with SoA will be assessed by LCA.**
  - **Technologies for improvement of composite properties, e.g. nano particles/ cellulose, plasma need to be included.**

ECO-COMPASS


Recycling Fibre
(e.g. carbon)
Bio-Fibre
(e.g. Ramie, Flax)
Characterization,
Modelling and Simulation
Energy
recovery
Eco-Reinforcement
(e.g. hybrid non-woven)
Eco-Composite
Manufacturing
Use-Phase
(e.g. secondary structure)
End of Life
Recycling /
Energy recovery
Bio-Resin
(e.g. Epoxy)
Hybrid
Sandwich Core
Material Protection Technologies
(e.g. fire/moisture coatings)
Processability and Compatibility
(e.g. nano cellulose, plasma treatment)
Multifunctionality
(e.g. conductivity by interlayer or additives)
Life Cycle Assessment
LCA

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谢谢大家的关注。

THANK YOU FOR YOUR ATTENTION.

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