Task 5: Materials and the Environment + Processes

Instructions: Check the following questions and exercises. Read chapter 15 of 4th edition of the course textbook about Materials and the environment, as well as chapters 13 and 14 about processes and process selection.

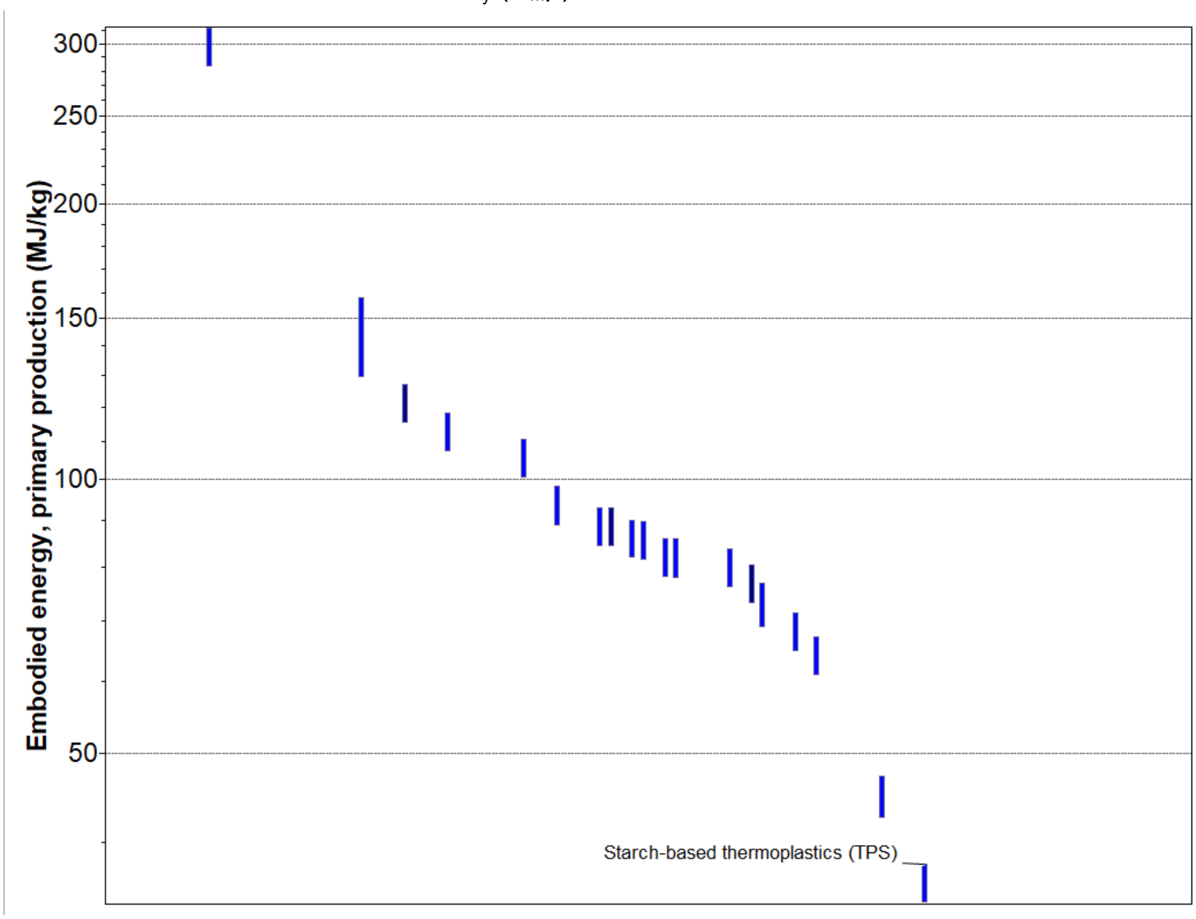
Criterion: A good report on this task demonstrates a good understanding of:

- how the complexity of auditing the environmental impact of a product is amenable to simplifications that can be evaluated already in the design phase (Task 5.1)
- how materials selection is constrained by production processes and vice versa (Task 5.2)

Task 5.1: Auditing the environmental impact:

Task 5.1.1: Estimate the amount of energy in different polymers. Which polymer embodies the least energy during its manufacture, when a Young's modulus value of at least 0.8 GPa is required? Solve the task with the level 2 map.

First we filtered out Polymers and minimum Young's modulus as 0.8 GPa
Then, we plot Embodied Energy, primary production * Density as the Y-axis, Young's modulus as the X-axis. The material index is $\sigma_y/(H_m\rho)$ and we need to maximize it



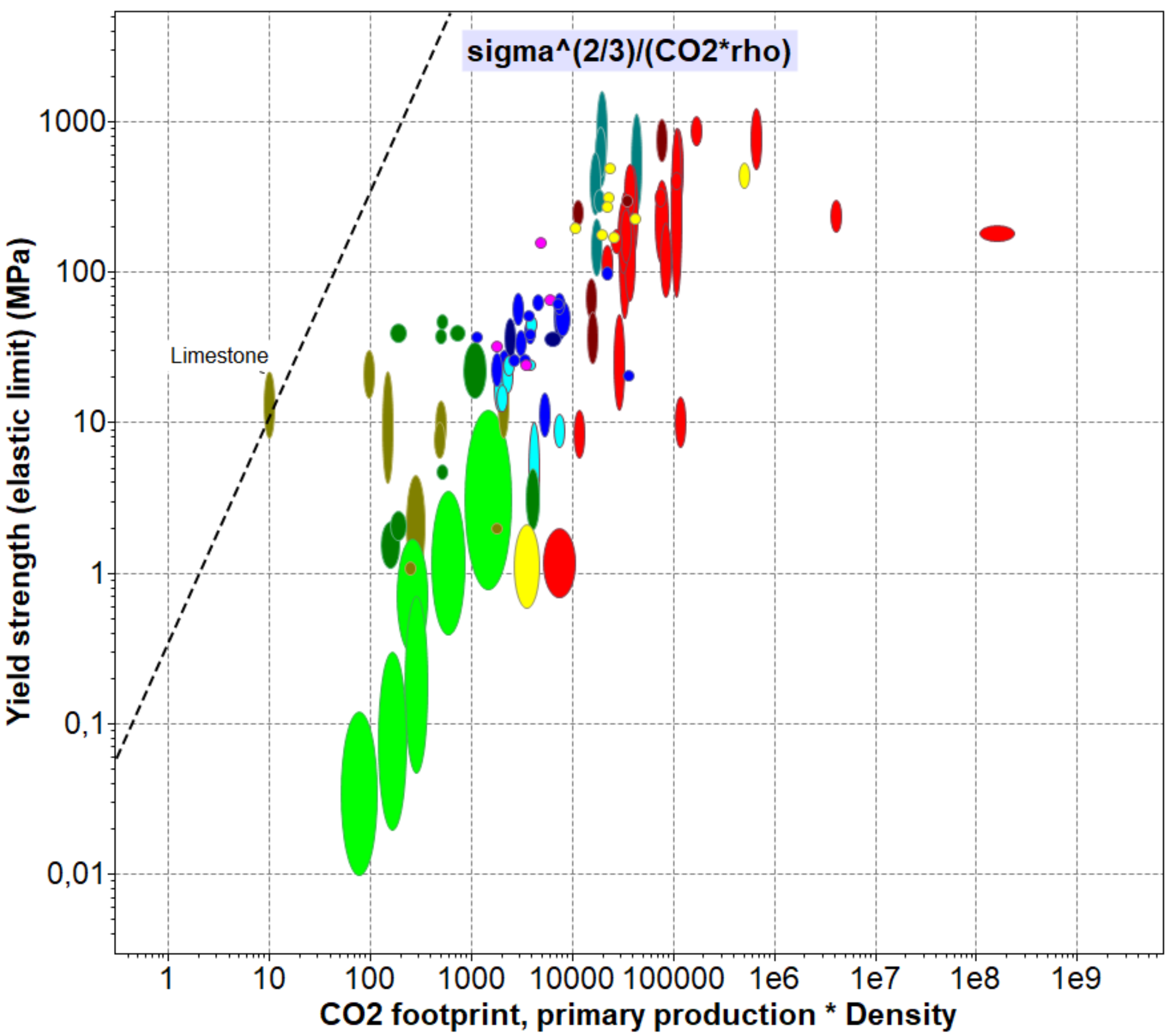
The polymer embodies the least energy during its manufacture is Starch-based thermoplastics

Task 5.1.2: Draw up a map with which you can compare different materials with, regard to beam strength (in bending) versus CO_2 emissions. Which material possesses the smallest carbon footprint compared to strength? Also, draw up this map for beam strength versus CO_2 emissions when recycled material is used. Briefly discuss the differences between these maps.

The best materials for a beam of specified bending strength and minimum CO2 footprint are those with large values of

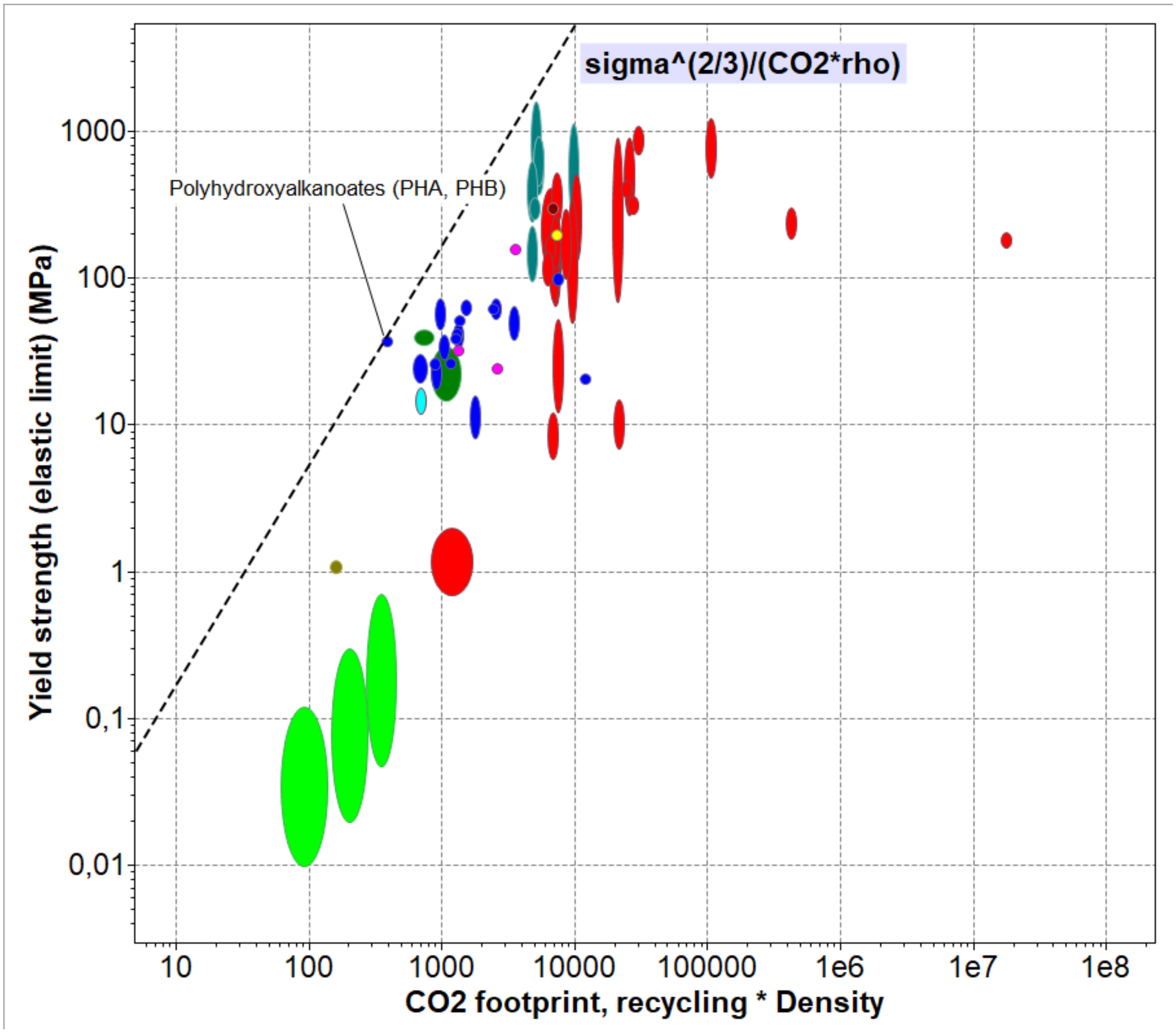
$$M = \frac{\sigma_f^{2/3}}{CO2\,\rho}$$

where σ_f is the strength of the beam material. Other indices follow in a similar way. We need to minimize the carbon footprint CO2 per unit of function. This graph is plotted using Database Level 2 materials. The first graph uses the CO2 footprint without recycling



We can see that Limestone is the best material that maximizes the index

Now this time we also consider recycling. The second graph uses the CO2 footprint with recycling, and the best materials are PHA and PHB.



The differences between these maps:

1. The second map appears to be lacking some materials, probably being overlapped by other material groups, or not having entry data in CO2 footprint recycling
2. Stones and bricks have low carbon footprint but can't be recycled.
3. Natural materials also show the same property: Low footprint but also harder to recycle.

Task 5.1.3: The blades of a wind turbine are quite heavy, massive structures. It requires specialized forms of transport to load and carry these structures to their destination. Evaluate the energy consumption and CO_2 emissions of wind turbine blades of the same size but made from different materials (Glass-reinforced plastic (GRP), Carbon-fiber-reinforced polymers (CFRP), and aluminum), when transported 2600 km from Rotterdam, Netherlands to Oulu, Finland with a semi-trailer truck as shown in Figure 1.

Material	Length	Max. height/ width	Mass
GRP	30 m	3 m	**2400 kg**
CFRP	30 m	3 m	**2430 kg**
Al	30 m	3 m	**4320 kg**

Hint: *The **eco audit tool** in GRANTA software is designed to do these kinds of calculations.*

Figure 1 A semi-truck loading the wind turbine blade to transfer.

Truck Code name meaning

Euro 3: Introduced in 2000 for passenger cars and 2001 for trucks. It set limits on nitrogen oxides (NOx) and particulate matter (PM).

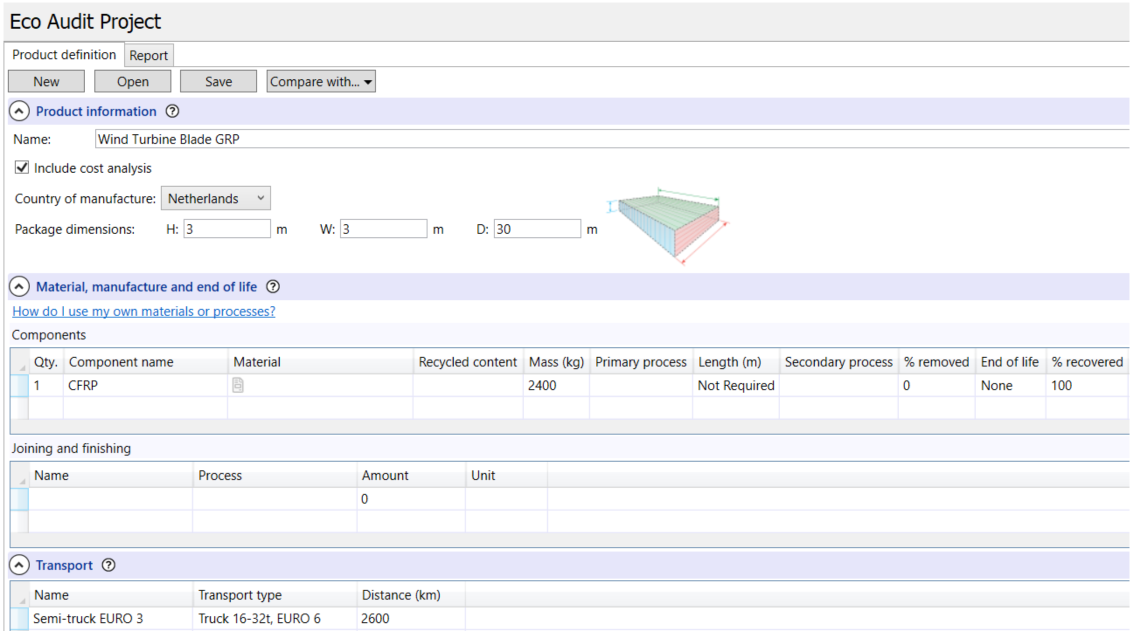
Euro 4: Introduced in 2005 for passenger cars and 2006 for trucks. It further reduced the allowable limits of NOx and PM.

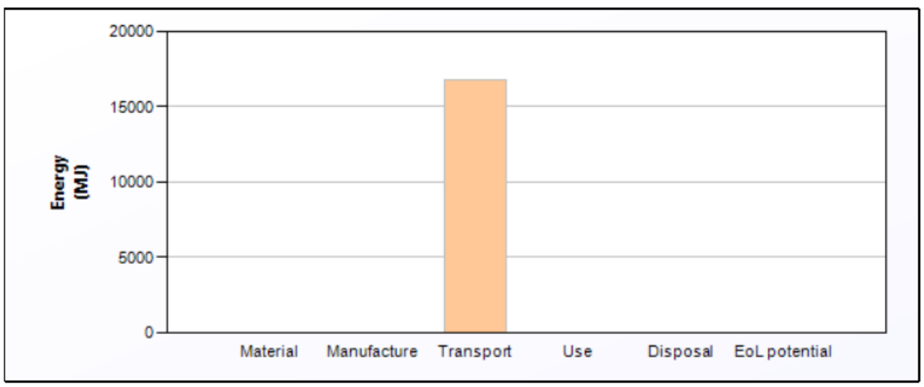
Euro 5: Introduced in 2009 for passenger cars and 2010 for trucks. It had even stricter limits, especially for diesel vehicles, and introduced limits for ammonia (NH3).

Euro 6: Introduced in 2014 for most vehicles. It has the strictest limits, especially concerning NOx emissions from diesel engines.

Therefore, it is always good to choose Truck Euro 6 type.

I. GRP Transport figures

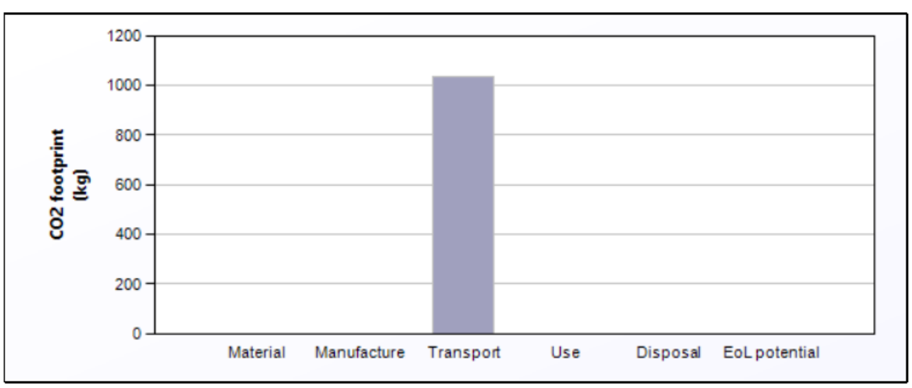




	Energy (MJ/year)
Equivalent annual environmental burden (averaged over 1 year product life):	1,67e+04

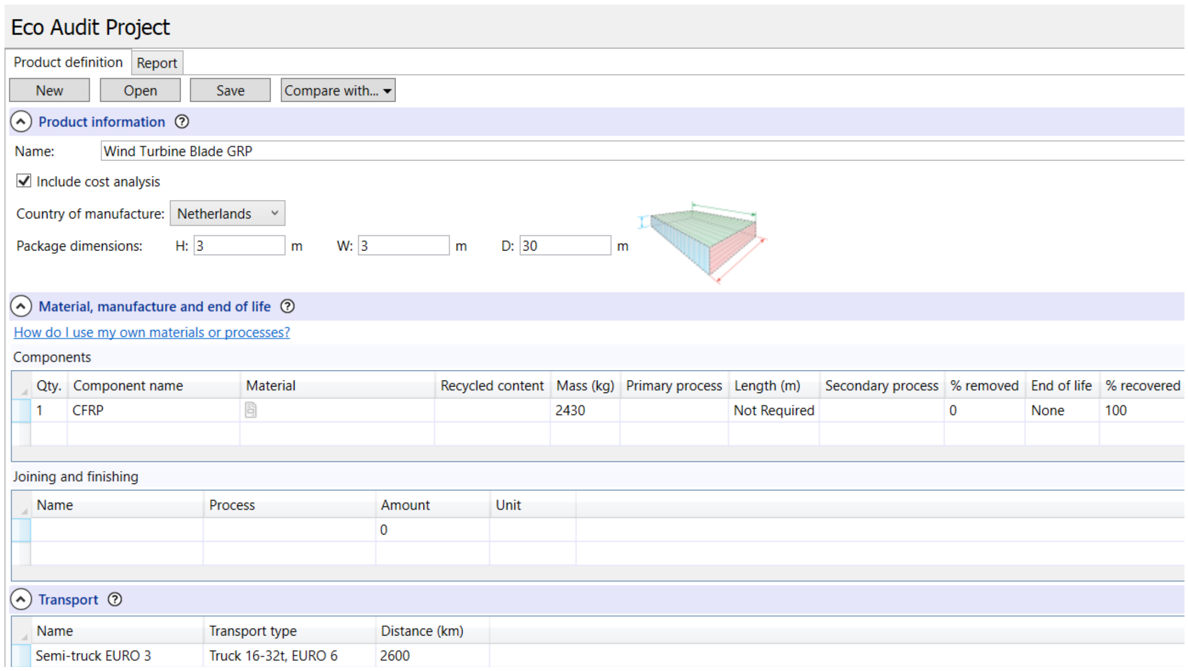
CO2 Footprint Analysis

Summary



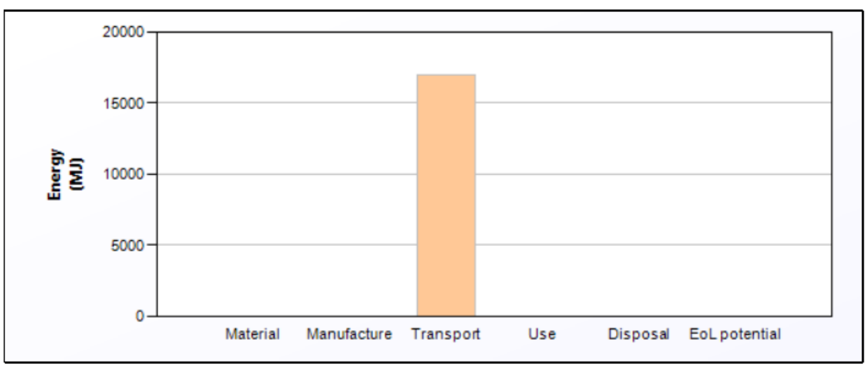
	CO2 (kg/year)
Equivalent annual environmental burden (averaged over 1 year product life):	1,04e+03

II. CFRP Transport figures



Energy Analysis

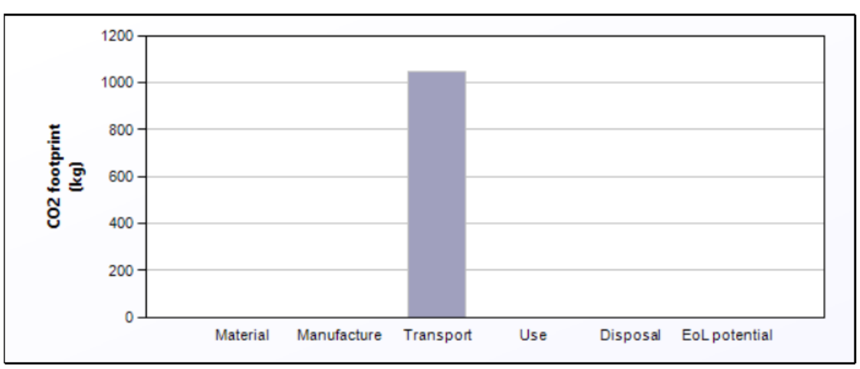
Summary



	Energy (MJ/year)
Equivalent annual environmental burden (averaged over 1 year product life):	1,69e+04

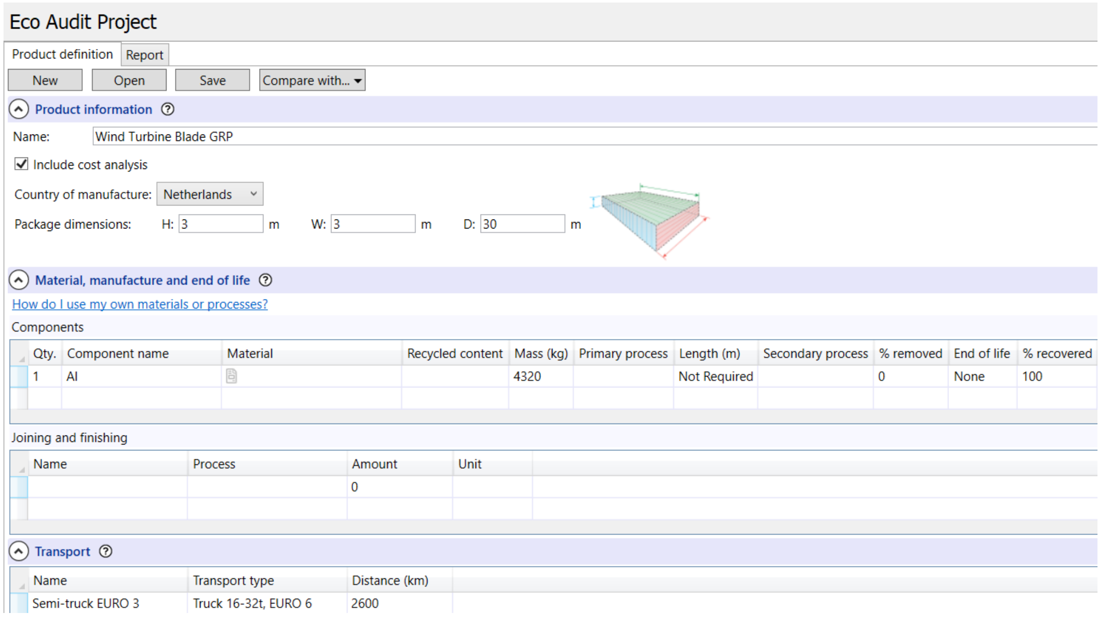
CO2 Footprint Analysis

Summary



	CO2 (kg/year)
Equivalent annual environmental burden (averaged over 1 year product life):	1,05e+03

III. Al Transport figures



Eco Audit Project

Product definition | Report

New | Open | Save | Compare with...

Product information

Name: Wind Turbine Blade GRP

☑ Include cost analysis

Country of manufacture: Netherlands

Package dimensions: H: 3 m W: 3 m D: 30 m

Material, manufacture and end of life

How do I use my own materials or processes?

Components

Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process	Length (m)	Secondary process	% removed	End of life	% recovered
1	Al			4320		Not Required		0	None	100

Joining and finishing

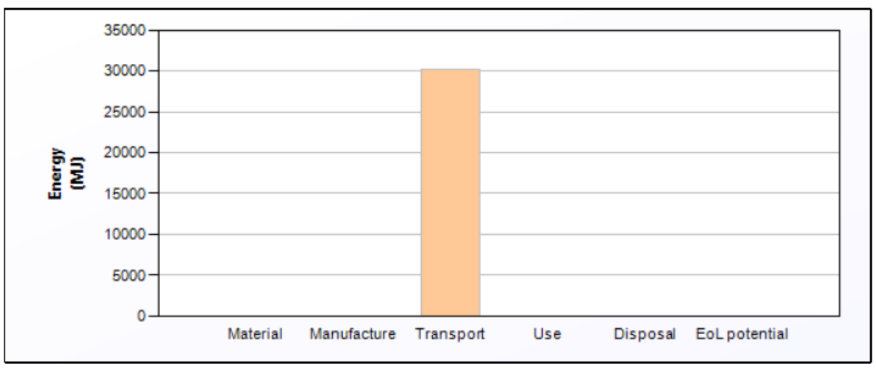
Name	Process	Amount	Unit
		0	

Transport

Name	Transport type	Distance (km)
Semi-truck EURO 3	Truck 16-32t, EURO 6	2600

Energy Analysis

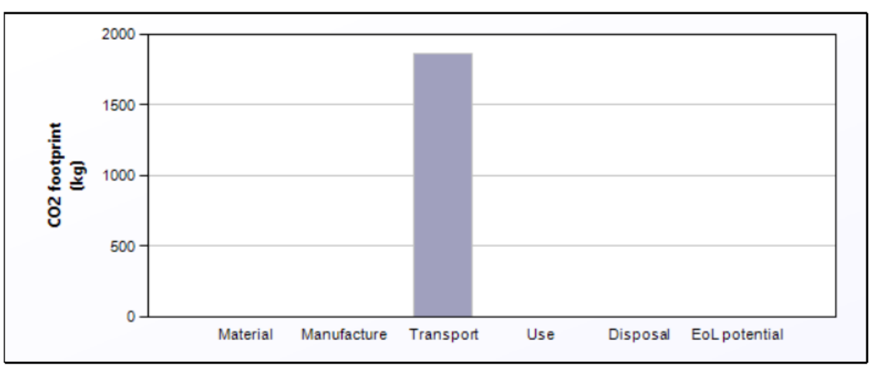
Summary



	Energy (MJ/year)
Equivalent annual environmental burden (averaged over 1 year product life):	3,01e+04

CO2 Footprint Analysis

Summary



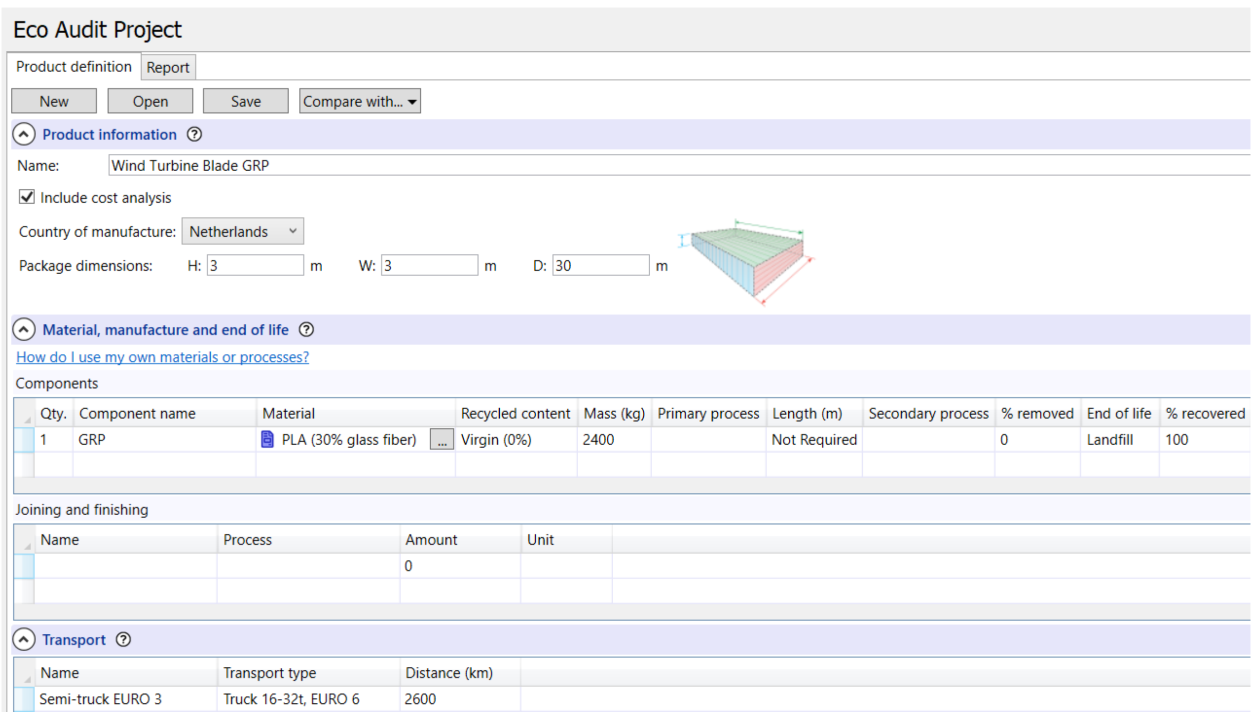
	CO2 (kg/year)
Equivalent annual environmental burden (averaged over 1 year product life):	1,86e+03

We can conclude that GRP and CFRP have nearly equal amount of energy consumption and CO2 emission, while aluminum wind turbine blade consumes twice those figures

Task 5.1.4: Evaluate the environmental impact of a GRP wind turbine blade. How does the end-of-life of the material affect the overall life-cycle expenses of the turbine blade? There is no recycling use of GRP and CFRP, but aluminum can be easily recycled. Does the situation change significantly if the turbine blade is made from aluminum and recycled in the end instead of going to landfill?

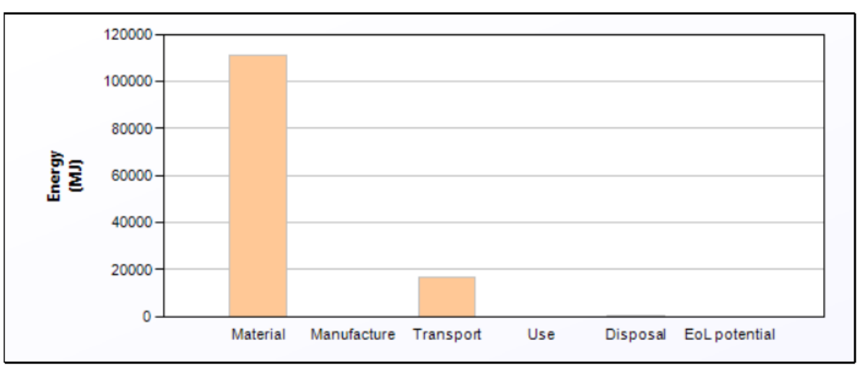
Here are the settings for the two materials, GRP and Aluminum

I. GRP Material and Transport figures



Energy Analysis

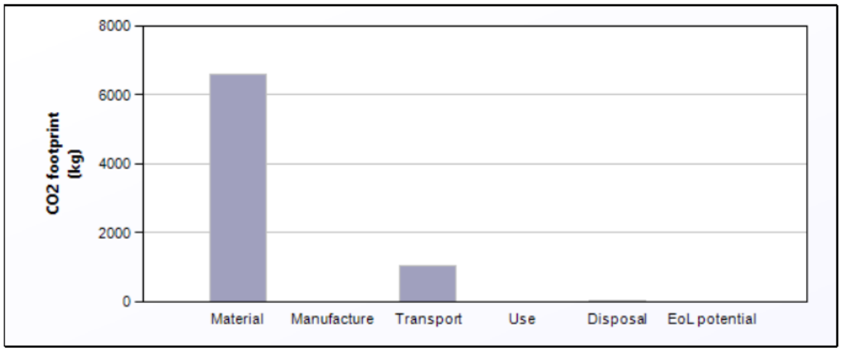
Summary



	Energy (MJ/year)
Equivalent annual environmental burden (averaged over 1 year product life):	1,28e+05

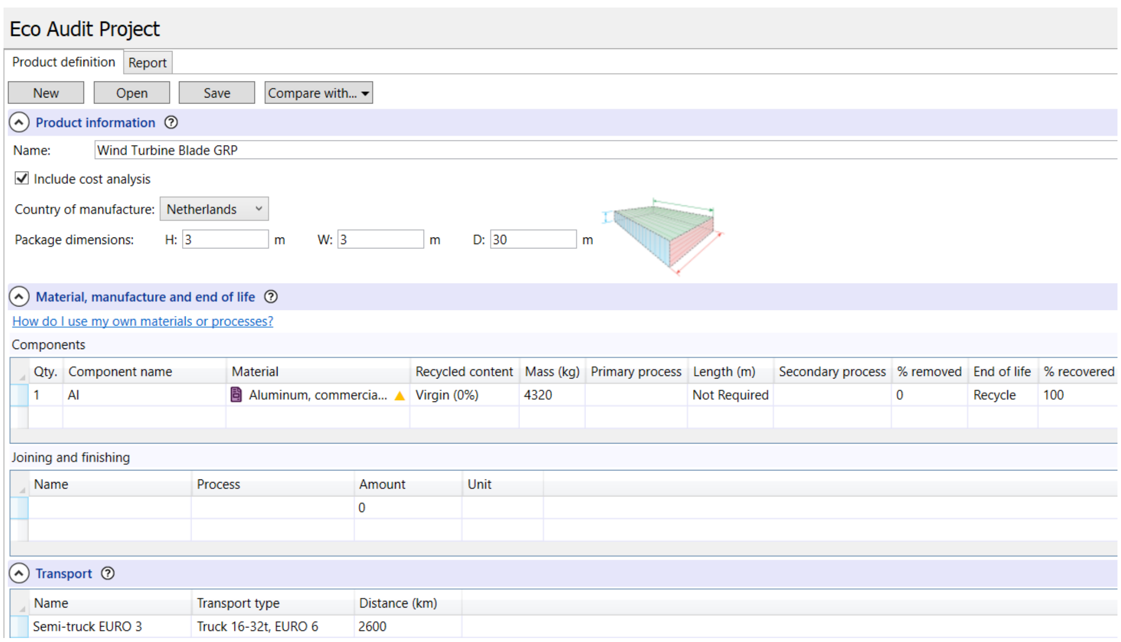
CO2 Footprint Analysis

Summary



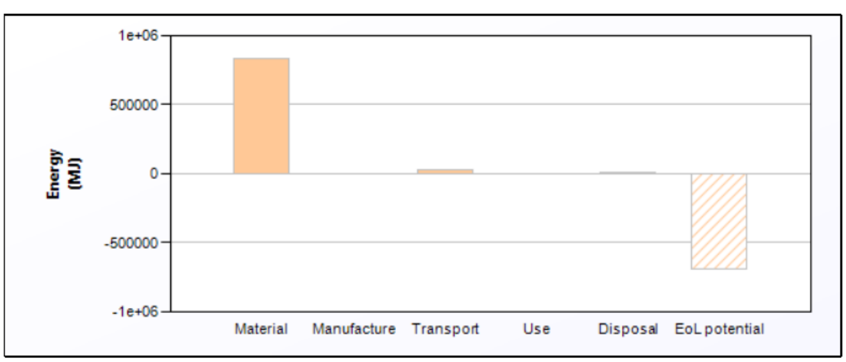
	CO2 (kg/year)
Equivalent annual environmental burden (averaged over 1 year product life):	7,65e+03

II. Aluminum Material and Transport figures



Energy Analysis

Summary



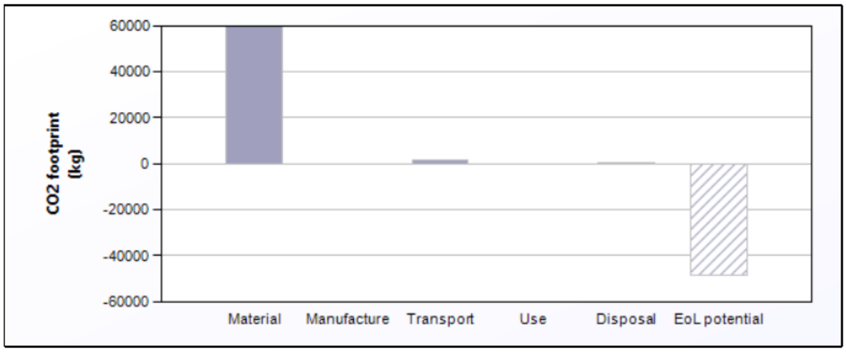
	Energy (MJ/year)
Equivalent annual environmental burden (averaged over 1 year product life):	8,68e+05

EoL potential:

Component	End of life option	% recovered	Energy (MJ)	%
Al	Recycle	100,0	-6,9e+05	100,0
Total			**-6,9e+05**	**100**

Net Energy of Aluminum: 8.68e+05 - 6.9e+05 = 1.78e+05 MJ/Year

CO2 Footprint Analysis Summary



	CO2 (kg/year)
Equivalent annual environmental burden (averaged over 1 year product life):	6,16e+04

EoL potential:

Component	End of life option	% recovered	CO2 footprint (kg)	%
Al	Recycle	100,0	-4,8e+04	100,0
Total			**-4,8e+04**	**100**

Net CO2 Emissions of Aluminum: 6.16e+04 - 4.8e+04 = 1.36e+04 kg

We can see that if End of Life is considered, where Aluminum is totally recycled while GRP is not recycled, then using Aluminum is not that more harmful to the environment than using GRP (1.78e+05 MJ/Year Energy and 1.36e+04 kg/Year CO2 Footprint), compared to GRP (1.28e+05 MJ/Year Energy and 7.65e+03 kg/Year CO2 Footprint)

Task 5.2: Selection of processes

From **task 0_1** you have chosen a material group and given **three examples** of materials representative of that group with corresponding examples of what they are used for.

My material group: Polymers in Elastomers

Polyethylene (PE):

- PE is widely used in household products and food containers. Common products made from PE are oil containers, street bollards, milk bottles, toys, beer crate, food packaging, shrink wrap, squeeze tubes, disposable clothing, plastic bags, paper coatings, cable insulation, artificial joints, and as fibers - low cost ropes and packing tape reinforcement.

Polylactide (PLA):

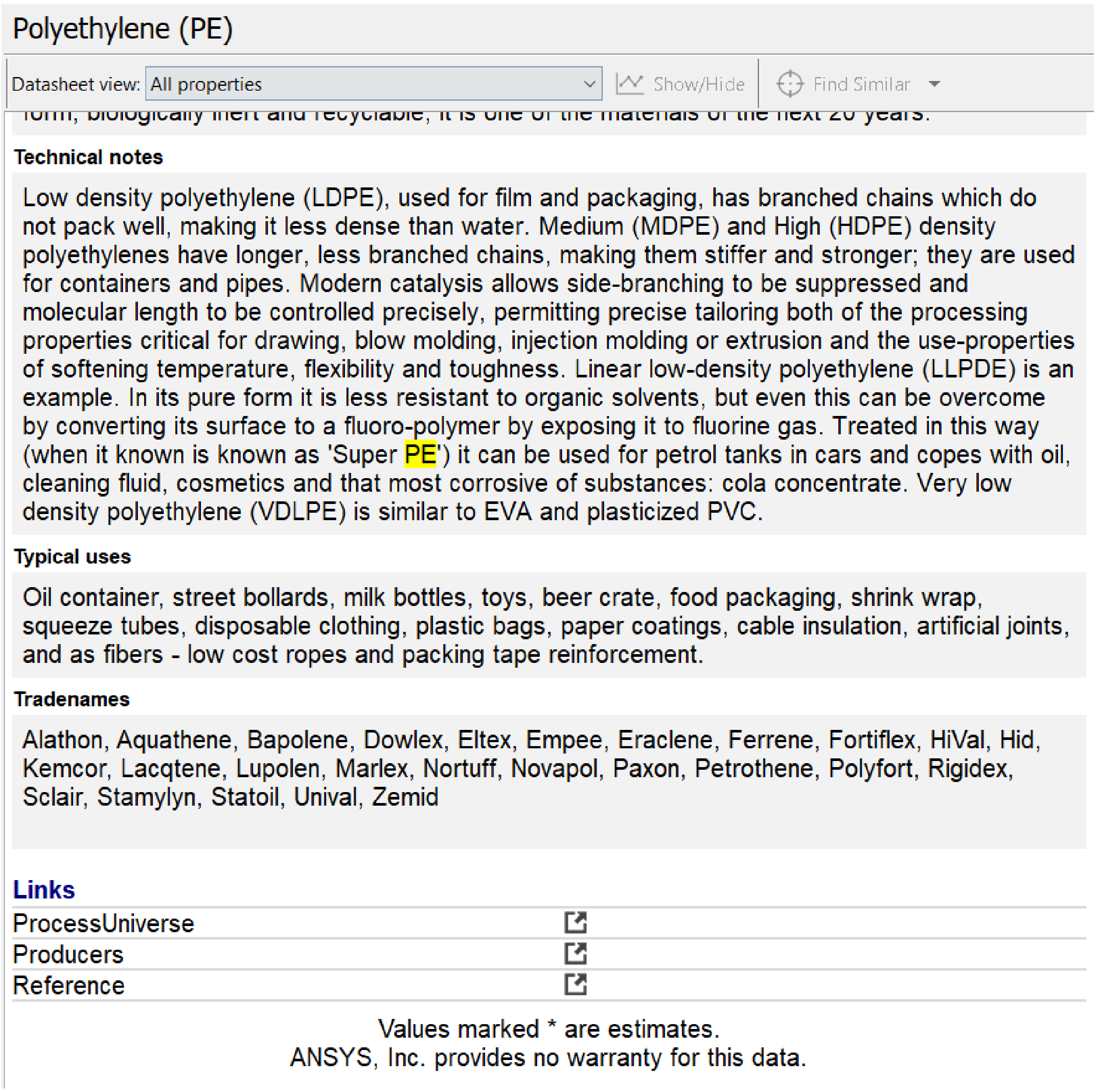
- Injection molded: pencil sharpeners, rulers, cartridges, toys, plant pots, plastic bones and other toys for pets, plastic cutlery, hair combs.
- Thermo-formed: trays for fresh food packaging, especially fruit and vegetables.
- Film extrusion: shopping bags, bubble film for wrapping, plastic laminates for paper cups and plates, bags for rubbish disposal, lining for baby nappies, mulching films for horticulture, wrapping for fruit, vegetables and sanitary products .

Polypropylene (PP):

- PP is used in a variety of applications: Ropes, automobile air ducting, parcel shelving and air-cleaners, garden furniture, washing machine tank, wet-cell battery cases, pipes and pipe fittings, beer bottle crates, chair shells, capacitor dielectrics, cable insulation, kitchen kettles, car bumpers, shatterproof glasses, crates, suitcases, artificial turf, thermal underwear.

Task 5.2.1: Look up the datasheets for the example materials in the GRANTA software, find the link to the “ProcessUniverse”, and explore the available information. Do this for all three example materials (or closely related materials) that you chose at Level 2 and Level 3.

For each material, open their descriptions and scroll to the bottom. We can see the ProcessUniverse hyperlink.



Polyethylene (PE)

Datasheet view: All properties   Show/Hide   Find Similar

form, biologically inert and recyclable, it is one of the materials of the next 20 years.

Technical notes

Low density polyethylene (LDPE), used for film and packaging, has branched chains which do not pack well, making it less dense than water. Medium (MDPE) and High (HDPE) density polyethylenes have longer, less branched chains, making them stiffer and stronger; they are used for containers and pipes. Modern catalysis allows side-branching to be suppressed and molecular length to be controlled precisely, permitting precise tailoring both of the processing properties critical for drawing, blow molding, injection molding or extrusion and the use-properties of softening temperature, flexibility and toughness. Linear low-density polyethylene (LLPDE) is an example. In its pure form it is less resistant to organic solvents, but even this can be overcome by converting its surface to a fluoro-polymer by exposing it to fluorine gas. Treated in this way (when it known is known as 'Super PE') it can be used for petrol tanks in cars and copes with oil, cleaning fluid, cosmetics and that most corrosive of substances: cola concentrate. Very low density polyethylene (VDLPE) is similar to EVA and plasticized PVC.

Typical uses

Oil container, street bollards, milk bottles, toys, beer crate, food packaging, shrink wrap, squeeze tubes, disposable clothing, plastic bags, paper coatings, cable insulation, artificial joints, and as fibers - low cost ropes and packing tape reinforcement.

Tradenames

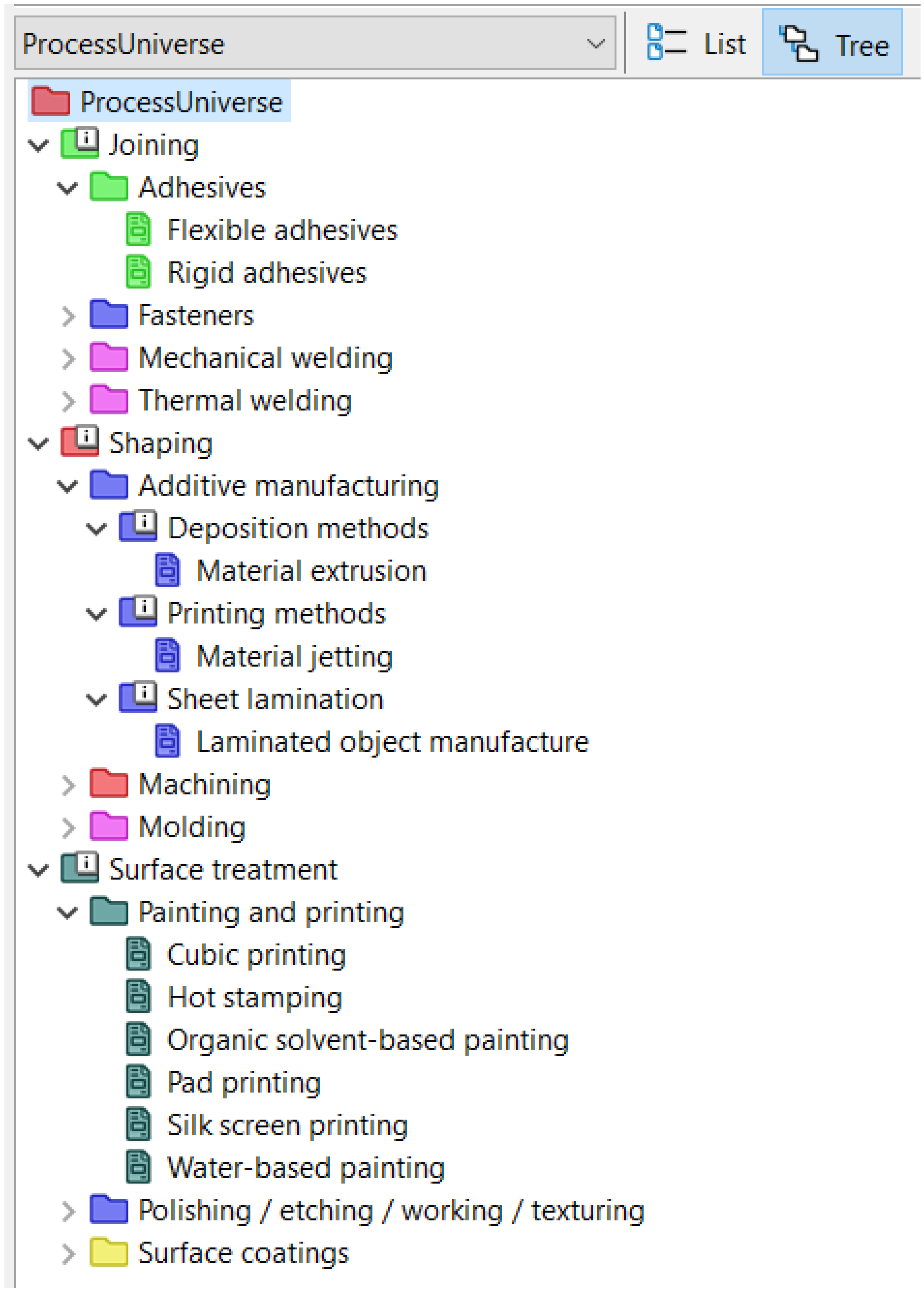
Alathon, Aquathene, Bapolene, Dowlex, Eltex, Empee, Eraclene, Ferrene, Fortiflex, HiVal, Hid, Kemcor, Lacqtene, Lupolen, Marlex, Nortuff, Novapol, Paxon, Petrothene, Polyfort, Rigidex, Sclair, Stamylyn, Statoil, Unival, Zemid

Links

ProcessUniverse
Producers
Reference

Values marked * are estimates.
ANSYS, Inc. provides no warranty for this data.

Then we can check the processes limit imposed by Granta.



I have done similarly for all 3 materials at both levels, but it's quite long so they are not included in this report.

Task 5.2.2: Choose three **joining processes**, three **shaping processes**, and three **surface treatment processes**. Make a table with these nine processes and the three example materials, indicating the suitability of each of those processes for each of those materials. Discuss your entries in this table. Briefly discuss the processes you chose, and what their advantages and disadvantages are, concerning materials, shapes, availability, cost, waste, and energy use. (For your report, just having the table is enough, but be familiar with the processes you have chosen, you will discuss them in the flipped classroom.) Reflect on the simplifications that the GRANTA software imposes at Level 2 and Level 3, on both materials and processes and how such simplifications help or hinder at different stages of the design process. Summarize your thoughts about that in the report.

In Database level 3, the specifications for the materials are all Glass-reinforced plastics:
PE-HD (30 % glass fiber)
PP (30 % long glass fiber)
PLA (30 % glass fiber)

In the table below, a tick means there's a process for this material, and a cross means otherwise

	Process	PE (II)	PP (II)	PLA (II)	PE (III)	PP (III)	PLA (III)
Joining processes	Hot gas welding	✓	✓	✓	✓	✗	✓
	Rigid adhesives	✓	✓	✗	✗	✓	✗
	Sewing	✓	✓	✗	✗	✗	✗
Shaping processes	Injection molding	✓	✓	✓	✓	✓	✓
	Extrusion	✓	✓	✗	✓	✓	✓
	Circular sawing	✓	✓	✓	✓	✓	✓
Surface treatment processes	Hot stamping	✓	✓	✓	✓	✓	✓
	Vapor metalizing	✓	✓	✓	✓	✓	✓
	Water-based painting	✓	✓	✓	✓	✓	✓

The short descriptions for each process:

1. Hot gas welding: A process where a hot gas stream, usually from a torch, is used to melt the joining surfaces of thermoplastics. The materials are then pressed together, forming a weld upon cooling.

2. Rigid adhesives: These are strong, non-flexible adhesives used to bond materials together. They provide a solid bond but lack flexibility, making them suitable for applications where movement isn't expected.

3. Sewing: A method of joining materials, typically fabrics, using a needle and thread. It's a versatile process used in textiles to create seams, attach patches, or add decorative elements.

4. Injection molding: A manufacturing process where molten material is injected into a mold to form a part. Once cooled, the part is ejected, making it a popular method for mass-producing complex shapes.

5. Extrusion: A process where material is pushed or drawn through a die of the desired cross-section. It's commonly used for producing long continuous products like pipes, rods, and profiles.

6. Circular sawing: A cutting method using a circular saw blade that rotates to cut materials. It's widely used in woodworking and metalworking for straight cuts.

7. Hot stamping: A process where heated dies are pressed onto a material to leave an imprint. It's often used for branding, decoration, or adding patterns to surfaces.

8. Vapor metalizing: A process where metal is evaporated and then condensed onto a substrate, providing a thin metallic layer. It's used for decorative finishes, protective coatings, or to create reflective surfaces.

9. Water-based painting: A painting method using paints where water is the primary solvent. These paints are environmentally friendly, emit fewer odors, and are easy to clean up.

The advantages and disadvantages of the chosen processes are:

Process	**Materials**	**Shapes**	**Availability**	**Cost**	**Waste**	**Energy Use**
Hot gas welding	✓	✗	✓	✓	✗	✗
Rigid adhesives	✓	✓	✓	✓	✗	✓

Sewing	✓	✓	✓	✓	✗	✓
Injection molding	✓	✓	✓	✗	✗	✗
Extrusion	✓	✓	✓	✓	✗	✗
Circular sawing	✓	✗	✓	✓	✗	✓
Hot stamping	✓	✓	✓	✓	✗	✗
Vapor metalizing	✓	✓	✗	✗	✗	✗
Water-based painting	✓	✓	✓	✓	✓	✓

For material, a tick means it can generally work with a wide variety of different materials.

- **Reflect on the simplifications that the GRANTA software imposes at Level 2 and Level 3, on both materials and processes and how such simplifications help or hinder at different stages of the design process**

Level 2:

Materials: a broader overview of materials, grouping them into families and providing average properties. It's more detailed than Level 1 but still generalizes materials to some extent.
Processes: Basic manufacturing processes are introduced as how materials can be shaped, joined, and finished. However, the details of each process are usually skipped.

Level 3:
Materials: the software offers specific materials within families, with more detailed data on properties, applications, and environmental impacts.
Processes: More advanced and specialized processes. There's more groups and details of each process, its advantages and suitable applications. It's suitable for real applications

Task 5.2.3: Now choose **one of the use cases** you considered for **task 0_1**. Explain how such products are made. (No need to go into large details, approximately 200-300 words with one or two illustrations is good.)

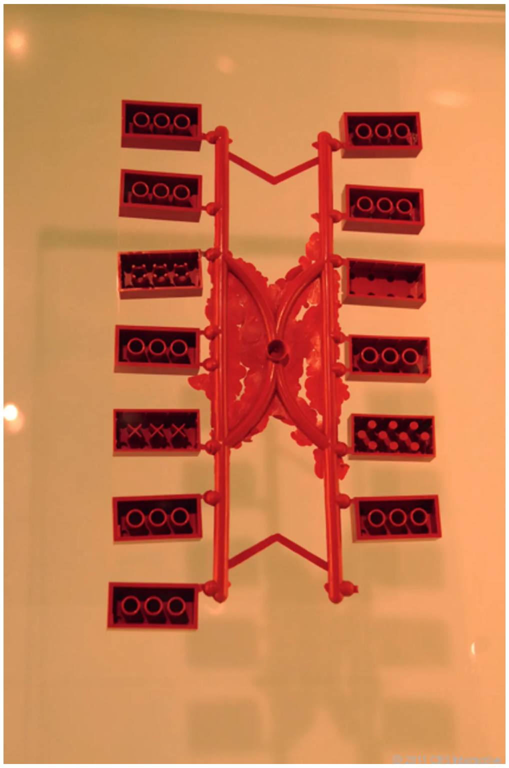
Manufacturing LEGO Bricks from Polyethylene (PE): [1]

The process starts with plastic chunks called granules in many colors. From the silos at the factory, the plastic granules are fed down pipes to the molding machines.

Inside the molding machines, the granules are superheated to a temperature of about 230°C. This melted plastic goo is poured into molds, little metal containers shaped like hollow LEGO bricks. The molding machine applies pressures of hundreds tonnes to ensure precise shape for the bricks. After molding, the bricks are cooled and ejected, which takes about 10 seconds.

Because of the dangerous conditions and high precision required, the molding process is almost completely automated. Finished pieces roll down conveyor belts into boxes. The next stop in the manufacturing process is the assembly halls where details are printed on and multi-part pieces are put together.

The final step is putting all the right pieces together to make complete LEGO sets. Boxes called cassettes roll on conveyor belts underneath the bins that hold each type of piece. The bins open and close to release the right number of pieces into each cassette. Finally, packing operators fold the boxes, add additional pieces and the building instructions and watch out for any machine-made mistakes.


Injection molding of Lego bricks [2]

Reference:
[1]
https://www.lego.com/ms-my/service/help/fun-for-fans/behind-the-scenes/brick-facts/how-are-lego-toys-made-blt0cb8fe682c26474e?locale=ms-my
[2] https://www.cnet.com/pictures/behind-the-scenes-at-legos-private-museum-photos/