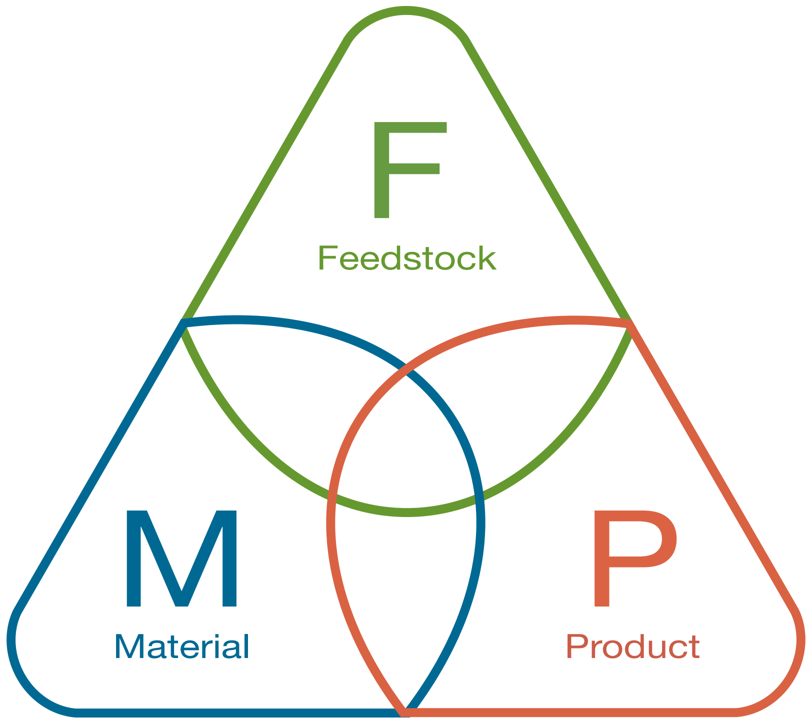

FMP-framework & FMP-canvas

Version 1.0

December 2025

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ams-institute.org/urban-challenges/circularity-urban-regions/fmp/

Feedstock-Material-Product framework
&
Feedstock-Material-Product-canvas

The FMP-framework

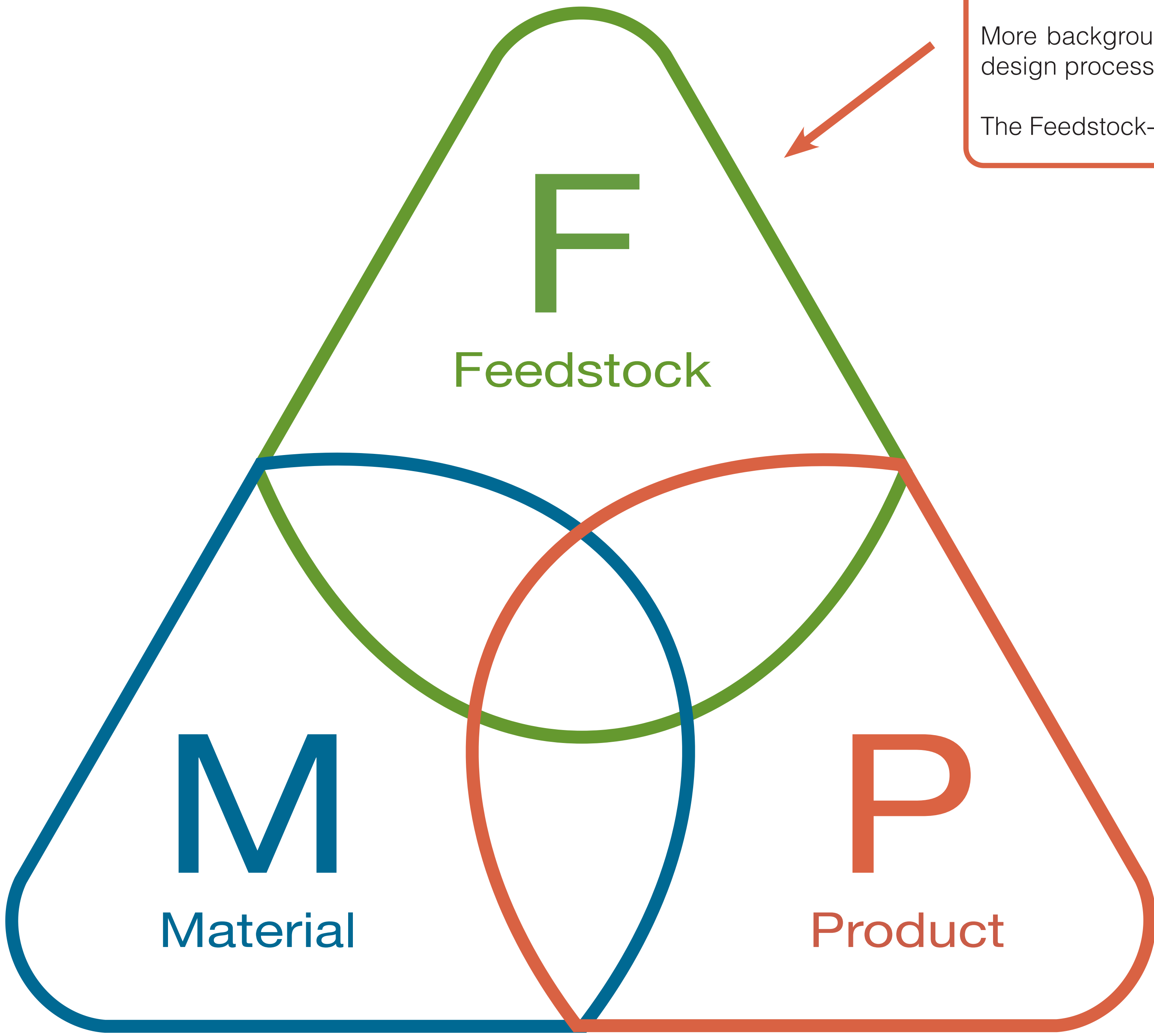
The aim of the FMP-framework is to improve decision making in designing biobased materials and products for a circular bioeconomy.

To replace fossil based products, biobased products must meet numerous technological, environmental, market, physical, and social criteria. Multiple of these criteria relate to the interfaces of the feedstock, material and/or product level. An example is recycling as end-of-life possibility, where high value retention of materials can only be achieved when materials can be separately harvested from a product.

As essential criteria that decide whether or not a product has true value in a circular bioeconomy touch upon the interface of the feedstock, material and/or product level, the trinity of feedstock, material and product takes a central place in the FMP-framework.

More background information on the need for placing the feedstock, material and product trinity in the center of the design process, can be found in this opinion paper.

The Feedstock-Material-Product (FMP) framework is developed by Mariet Sauerwein and Peter Mooij at AMS Institute.



The FMP-canvas

The FMP-canvas in this document is a practical tool based on the FMP-framework to facilitate decision making in biobased product design.

This canvas presents criteria to consider in biobased product design. These criteria are grouped according to the level(s) (feedstock, material and/or product) they touch upon.

The FMP canvas can act as a tracking tool throughout your research and design process. Initially, the canvas can be used as a quick-scan to identify strength and weaknesses of your selected feedstock, material and product. Most likely, you will not be able to answer the questions in the FMP-canvas in detail in this stage.

During the development process, you can return to the canvas to iteratitvely improve your answers. Furthermore, the canvas can be used as a communication tool to facilitate the discussion between feedstock suppliers, material experts and product designers.

Insights obtained from the canvas will hopefully speed up your reseach and design process, or provide arguments to opt for a different combination of feedstock, material and product.

The FMP-canvas is a living document, and feedback and suggestions via e-mail are highly appreciated.

See next page

Feedstock-Material-Product CANVAS

December 2025 - Version 1.0

digital version at

ams-institute.org/urban-challenges/circularity-urban-regions/fmp/

Criteria for Feedstock - Material

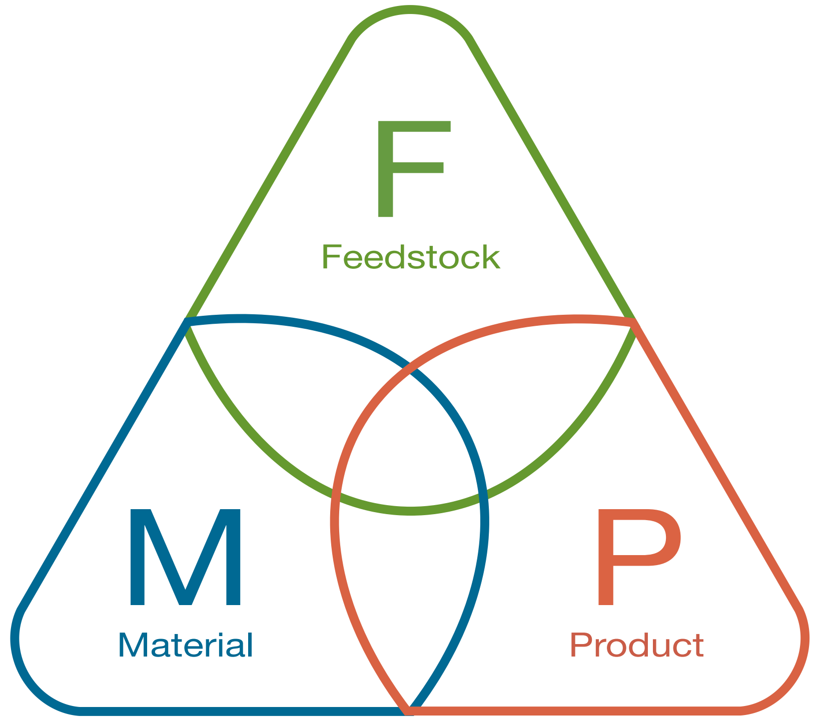
- What pretreatment steps are needed on feedstock level?
- What waste is generated during production?
- Is biodegradation a possible end-of-life strategy for your material?

Criteria for Material

- What production techniques are needed / possible on material level?
- What is the experiential characterization of the material?
- Via which end-of-life strategy can the material be recycled?

Criteria for Feedstock

- On which location(s) is your feedstock available?
- What volume of feedstock is available, and how consistent is it?
- Which part of the feedstock is used, what is done with the rest?
- Are there competing processes for this feedstock?



Criteria for Material - Product

- Which material inconsistencies are acceptable for the product?
- Does the product exploit the unique material characteristics?
- Via which end-of-life strategy can the material be recovered from the product?

Criteria for Feedstock - Material - Product

- Can feedstock deliver material with sufficient properties for product?
- What are the cost and the value?
- Which actors are involved?
- What is the user acceptance?
- What is the overall CO_2-emission?
- What is the impact on the nitrogen and phosphorus cycle?
- What is the impact on the water and soil quality?
- What is the impact on biodiversity?
- How much water is used in producing your FMP?
- Are there toxicity issues with your FMP?
- What is the energy consumption?
- What are the working conditions in all steps of your FMP?

Criteria for Product - Feedstock

- How do product market volume and feedstock availability relate?
- Are there legal regulations concerning using this feedstock for this product?
- Is biodegradation a possible end-of-life strategy for your product?

Criteria for Product

- Is the product scalable?
- How to prevent overproduction / production waste?
- Via which end-of-life strategies can the product lifetime be extended?
- Can the energy content of the product be recovered?

Choose your Feedstock, Material and Product

To use the FMP-canvas it is essential to choose your feedstock, material and product. In general, we use the following definitions for feedstock, material and product:

- Feedstock: resources that serve as input for the material
- Material: processed resources that are suitable for manufacturing
- Products: components for manufactured artefacts that fulfil a function

To facilitate choosing your feedstock, material and product, it is most easy to first define product, then material(s) and then consider the feedstock(s), and the CO_2-to-feedstock chain. Please see the suggestions below to help choosing product, material(s) and feedstock(s).

1. What is your product-component?
Virtually all products consist of multiple products components. For example, a wooden window frame will have metal nuts and bolts holding it together, and a bioplastic chair could consists of a bioplastic frame, a woollen cushion, leather arm rests and anti-scratch rubber feet.

For the sake of clarity, the FMP-canvas focusses on one product-component.

Products that combine two product components, e.g. a wooden façade panel with a flax insulation mat on the inside, are treated as two product-components: 1) a wooden façade panel and 2) a flax insulation mat. For both of these product components the corresponding material(s) and feedstock(s) can be defined, and two FMP-canvasses can be filled in.

Possible product-components include: façade panels, arm rests, cutlery

2. What material is your product-component made of? Do you have a mono-material or a composite?
Some product-components are made from a mono-material, e.g. a wooden window frame can be made from one type of wood.

In other cases, the product-component will be made from a composite material, which itself is a combination of several materials. A biobased façade panel (the product component) can be made from a reed fibre-alginate-calcite-bio composite (the main material), which consists of reed fibres, alginate and (non-biobased) calcite (the sub materials).

Possible materials include bio composites, bioplastics, cross-laminated timber, natural fibres, plate material, 3D print filament, etc.

3. What feedstock is needed to generate your material?
In the case of a mono-material, there is one feedstock. A wooden window-frame (product-component) can be made from oak wood (material) which is sourced from an oak tree (feedstock).
In the case of a composite material, there will be a feedstock for all sub-materials. The sub-materials 'reed fibres' and 'alginate' from the above example are produced from the respective feedstocks 'reed' and 'seaweed'. (Calcite is regarded biobased if produced from shells, but not if produced from calcium-carbonate rich rocks, produced from calcium-carbonate rich materials, but this is not a biobased feedstock and hence not further discussed).

4. What is the difference beteen feedstock and the CO_2-to-feedstock chain?
All biobased feedstocks are in ultimately made from CO_2 with the energy from sunlight in photosynthesis. For some of feedstocks, this is relatively straightforward chain, for example:

CO_2 + sunlight → oak tree → oak wood

In this example *oak wood* is the feedstock, while *CO_2 + sunlight → oak tree → oak wood* is the CO_2-to-feedstock chain.

For other feedstocks the CO_2-to-feedstock chain takes more steps, for example:

CO_2 + sunlight → corn → cow → leather → leather waste

In this example the *leather waste* is the feedstock, while *CO_2 + sunlight → corn → cow → leather → leather waste* is the CO_2-to-feedstock chain.

5. Should only the feedstock or the CO_2-to-feedstock chain be considered?
This differs per aspects in the FMP-canvas. In some cases, e.g. the availability of the feedstock, only the feedstock is relevant. If the working conditions for production of the feedstock are considered this touches upon the entire CO_2-to-feedstock chain. Whether or not an aspect FMP-canvas relates to feedstock or CO_2-to-feedstock chain is indicated in the canvas.

Please find below some examples of FMP-combinations, and the corresponding CO_2-to-feedstock chain for mono-materials.

	*CO_2-to-**feedstock** chain*	*Possible sub-materials and **final material***	***Product** (component)*
1	CO_2 + sunlight → **wood**	**CLT**	**window frame**
2	CO_2 + sunlight → **reed**	**reed fibre**	**insulation mat**
3	CO_2 + sunlight → food → **waste water**	**PHA**	**food container**
4	CO_2 + sunlight → hemp → **hemp residues**	**mycelium**	**mycelium based packaging**

Please find below some examples of FMP-combinations, and the corresponding CO2-to-feedstock chain for composite material. Please note that for composite materials multiple FMP-canvasses have to be filled in.
For example 5, the following two FMP's have to be assessed:

- leather waste - PHA leather fibre briocomposite - arm rest for chair
- waste water - PHA leather fibre briocomposite - arm rest for chair

	*CO_2-to-**feedstock** chain*	*Possible sub-materials and **final material***	***Product** (component)*
5a	CO_2 + sunlight → corn → cow → leather → **leather waste**	PHA + Leather fibre → **PHA – leather fibre biocomposite**	**Arm rest for chair**
5b	CO_2 + sunlight → food → **waste water**		
6a	CO_2 + sunlight → food → **sugar cane**	PLA + Cellulose → **PLA-cellulose composite**	**traffic sign**
6b	CO_2 + sunlight → wood → **wood waste**		
7a	CO_2 + sunlight → olive → **olive pit**	Olive pit powder + oystershell + alginate → **Paste for 3D printing**	**Lampshade**
7b	CO_2 + sunlight → plankton → oyster → **oystershell**		
7c	CO_2 + sunlight → seaweed → **alginate**		

Please define below your product-component, your material(s), your feedstock(s) and the corresponding CO_2 to feedstock chain.

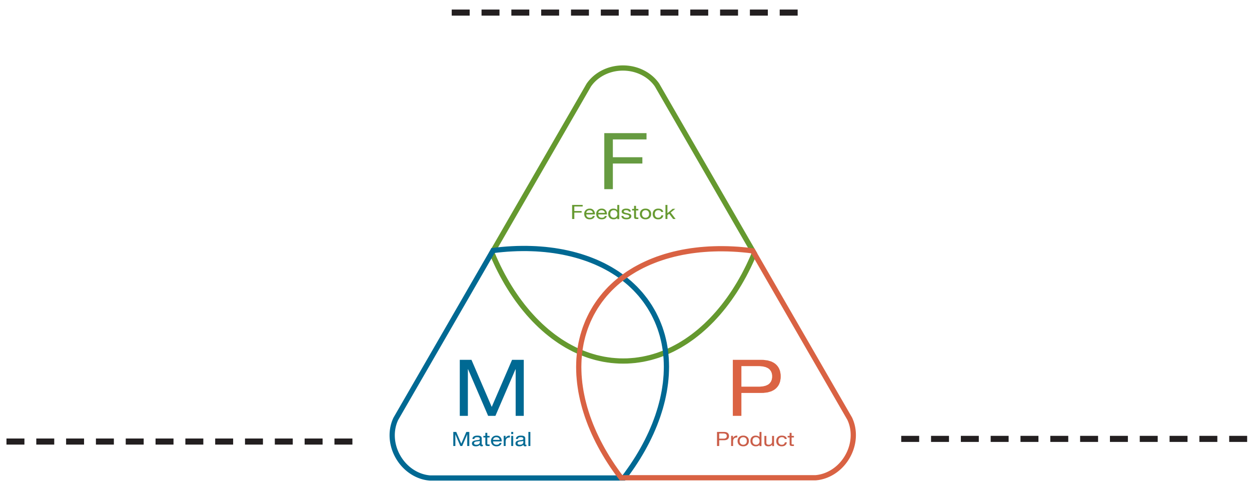
What is your **product component?**

What is your **material**? Is it a mono-material or a composite? If it is a composite, what is the final material, and what are the corresponding sub-materials?

For your material(s): what is the corresponding **feedstock**?

For your feedstock(s): what is the corresponding **CO_2-to-feedstock-chain?**

Please fill in your feedstock, material and product.



Feedstock

On which location is this feedstock available?
feedstock

At which precise location is your feedstock available (e.g. waste water treatment plant in a city, agricultural ground with soil rich in salt)? Is your feedstock on one place available (only city X), or at multiple places (city X, Y and Z)?

Preferred format answer: precise location(s)

What volume of feedstock is available, and how consistent is it?
feedstock

Is your feedstock continuously available, or in batches? What is the typical batch size? How much is available? Is your feedstock year-round available or are there (seasonal) variations in quantity?
Are there qualitive fluctuations in your feedstock between different batches?

Preferred format answer: amount feedstock / batch, # batches / year, or amount feedstock / year, seasonal variations, quality

Which part of the feedstock is used, what is done with the rest?
CO_2-to-feedstock chain

Do you use the entire feedstock, or only a part (e.g. only the fibres of hemp)? What can be done with the rest of the feedstock? Are there any other inevitable side streams in the CO_2-to-feedstock chain related to your feedstock? What happens with those?

Preferred format answer: part of feedstock used, possibilities rest

Are there competing processes for this feedstock?
feedstock

What other applications are there with this feedstock? Is your use more 'valuable'?

There are several biomass value pyramids, based on different definitions of 'value'. A traditional biomass value pyramids (see here) focusses on the economic value and hence places pharma at the top, while a biomass value pyramid that focusses on societal value, cascading and the time span CO_2 is stored in the bottom (see here) puts soil improvement at the top.

The value pyramid of Natuur & Milieu is the following.

1. Soil improvement
2. Food
3. Feed
4. Materials
5. High temperature industry
6. Mobility & Transport
7. Heat for the build environment
8. Electricity production & other heat production

Preferred format answer: place of your intended feedstock use in biomass value pyramid

Feedstock - Material

What pretreatment steps are needed on feedstock level?
feedstock

What pretreatment steps are needed with your feedstock to make it suitable for material production? Pretreatment steps could include drying, washing, seaving or leaching.

Preferred format answer: pre-treatment steps

What waste is generated during production?
feedstock

Is there waste generated during the production of the material from the feedstock (e.g cutting waste, scraps). What happens with this waste? How much waste is produced?

Preferred format answer: amount of waste / amount of feedstock, waste processing

Is biodegradation a possible end-of-life strategy for your material?
CO_2-to-feedstock

In biodegradation a material is broken down in CO_2, water and other inorganic compounds via for example anaerobic digestion or composting. Consequently, this CO_2 can be used for novel feedstock production. Under what conditions is your material biodegradable? And in what time? Some typical biodegradation times can be found here.

Preferred format answer: yes / no, if yes: under what conditions

Material

What production techniques are needed / possible on material level?

What production techniques are needed to transform your material in your product? Possible production techniques include (hot) pressing, injection moulding, extrusion and 3D printing.

Preferred format answer: production techniques

What is the experiential characterization of the material?

How do people experience your material in a sensorial, emotional and performative way? A useful toolbox for the experiential characterization can be the Ma2E4 toolkit.

Preferred format answer: experiential characterisation

Via which end-of-life strategy can the material be recycled?

Is it possible to either mechanically, chemically or biologically recycle your material?

More information on recycling strategies of bioplastics, typical biodegradation times and more can be found here.

Preferred format answer: intended end-of-life strategy to recycle material

Material - Product

Which material inconsistencies are acceptable for the product?

What material inconsistencies can occur, for example colour variations and smell? Are they acceptable for this product, and to what extent?

Preferred format answer: acceptable material inconsistencies

Does the product exploit the unique material characteristics?

What are the unique material characteristics? These could include functional properties (e.g. strength, biodegradability, fire retardancy) or experiential aspects (highly value look and feel). Material tinkering is a suitable method to find the unique material characteristics of your material.
How does your product exploit these characteristics?

Preferred format answer: unique material characteristics

Via which end-of-life strategy can the material be recovered from the product?

Is the product designed in such a way that the material can be used for refurbishing and remanufacturing? The R-ladder and Design for a circular economy (see Appendix A) provide further information.

Preferred format answer: material can be retrieved from product, and used for refurbishing & remanufacturing

Product

Is your product scalable?

Can your product be scaled up? What will be the first factor hindering further upscaling (e.g. feedstock availability, market demand)?

Preferred format answer: yes/no, factor hindering further upscaling

Can the energy content of the product be recovered?

Recovery of energy stands at the lowest place at the R-ladder. By incineration of a biobased product, the energy content of the product can be partly recovered.

Preferred format answer: yes/no, with argumentation

How to prevent overproduction and production waste?

The strategies ranked most sustainable in the R-ladder relate to refusing and rethinking the product, and reducing materials and other resources. How does your product relate to this strategies? Can your product for example be shared with others, or be used in multiple ways? Are new forms of ownership possible with your product? See Appendix A for further information.

Preferred format answer: strategies to prevent overproduction

Can the product lifetime be extended?

What options offers your product for reuse, repair, refurbishment, remanufacturing and repurpose? Those concepts stand at place four, five and six at the R-ladder (see Appendix A). Design for a circular economy provides relevant guidelines for this. Please note that EU-incentives concerning the right to repair could become legally binding in the near future. Further note that some of these strategies touch upon the material level as well. For the sake of simplicity, they are grouped under ‘product’

Preferred format answer: yes/no, with argumentation

Product - Feedstock

How do product market volume and feedstock availability relate?
feedstock

What is the expected market volume? How does this relate to the feedstock availability? Also consider seasonal availability of your feedstock?

Preferred format answer: market volume / year + feedstock availability / year

Are there legal regulations concerning using this feedstock for this product?
CO_2-to-feedstock

Are there rules and regulations concerning using your this feedstock for this purpose? Regulations could include the EU Waste Directive. Please note that from a certain feedstock some products could be legally allowed, while others are not. For example: medical products from bioplastic made from organic waste could not be allowed, while a park bench is.

Preferred format answer: legal regulations

Is biodegradation a possible end-of-life strategy for your product?
CO_2-to-feedstock

In biodegradation a product is broken down in CO2, water and other inorganic compounds via for example anaerobic digestion or composting. Consequently, this CO2 can be used for novel feedstock production. Under what conditions is your product biodegradable? And in what time? Some typical biodegradation times can be found here.

Preferred format answer: yes / no, if yes: under what conditions

Feedstock - Material - Product (1)

Can feedstock deliver material with sufficient properties for product?
feedstock

What product properties are required for the product and how does this translate to material and feedstock properties? Consider for example: strength, stiffness, density, biodegradability, UV resistance, weather resistance.
How will you measure this? What relevant norms are there for these properties? What equipment do you need? How do comparable materials score? If the material does not meet the required product properties, what post treatment steps (e.g. coating, painting) could you consider?

Preferred format answer: product properties, norms, equipment, ball park figures

What is the user acceptance of your FMP?
CO_2 to feedstock

What is the user acceptance of your FMP? What are aspects of your FMP that users value?

Preferred format answer: user acceptance

What are the cost and the value of your FMP?
feedstock

What are the overall economic cost of your FMP? How does this relate the cost of competing products?
Does your FMP offer additional value (e.g. good carbon or toxicity score) that are not standard taken in account in a traditional economic view? See True Price and Ecocost for methods to assign an economic price to these kind of values.

Preferred format answer: euro / kg product, price competing products, additional value FMP

What is the impact if your FMP on the nitrogen and phosphorus cycle?
CO_2 to feedstock

Does your FMP influence the nitrogen and/or phosphorus cycle? If so, to what extent?
A Life Cycle Assessment offers more insights than only kg CO2-eq/ kg product. The impact on the nitrogen and the phosphorus cycle are also impact categories for an LCA. See Appendix B for more information on LCA's.

Preferred format answer: kg N-eq / kg product, kg PO4 / kg product

Which actors are involved in your FMP?
CO_2 to feedstock

Who will use your product? What roles other actors (e.g. governments, universities) have to play to make your FMP a success?

Preferred format answer: actors involved + role

What is the overall CO_2-emission of your FMP?
CO_2 to feedstock

What amount of CO_2-equivalents / kg product is emitted, in all steps between initial carbon sequestration for your feedstock and product disposal? Which steps in your FMP emits most CO_2-equivalents? Are there reductions possible?
A Life Cycle Assessment (LCA) can calculate in detail the impact of all steps in your process from CO_2 to feedstock to material to product, and to end-of-life. A LCA does this for several categories, and is able to translate all these categories to the impact category Climate Change Total, with unit kg CO_2-eq / kg product. See Appendix B for more information on LCA's.

Preferred format answer: kg CO_2-eq / kg product

Feedstock - Material - Product (2)

What is the impact of your FMP on the water and soil quality?
CO_2 to feedstock

Is national or European regulation (e.g Kaderrichtlijn Water, Handelingsperspectief water en bodem sturend, EU) applicable to your FMP? If so, how does your FMP score on impact on water and soil quality?
For more detailed numbers on impact on water and soil quality, consider the impact categories land use-related impact/soil quality, eco-toxicity (freshwater), eutrophication of freshwater, eutrophication of seawater and eutrophication of land. See Appendix B for more information on LCA's.

Preferred format answer: impact on soil and water quality

What is the impact if your FMP on biodiversity?
CO_2 to feedstock

Does your FMP have an impact on biodiversity? Consider this for all steps between initial carbon sequestration and product end-of-life? Are there ways to minimize the possible negative impacts on biodiversity?

Preferred format answer: impact on biodiversity

Are there toxicity issues with your FMP?
CO_2 to feedstock

Does your FMP contain dangerous levels of toxic compounds? If so, will these compounds be released in your end-of-life strategy? You can consider the Safe by Design approach to tackle possible toxicity issues early in the design process.
For more detailed numbers on toxicity, consider the impact category 'Ecotoxicity (freshwater)', 'Human toxicity, carcinogenic' and 'Human toxicity, non-carcinogenic'. See Appendix B for more information on LCA's

Preferred format answer: toxicity + argumentation

How much water is used in producing your FMP?
CO_2 to feedstock

How much water is used for your FMP, in all steps between initial carbon sequestration for your feedstock and product disposal. Which steps in your FMP consume most water? Are there reduction possible?
For more detailed numbers on water usage, consider the impact category water use. See Appendix B for more information on LCA's.

Preferred format answer: kg water / kg product

What is the energy consumption of your FMP?
CO_2 to feedstock

How much energy is consumed in all steps between initial carbon sequestration and product end-of-life? Which process steps consume most energy? Are there viable ways to minimize this energy usage?
For more detailed numbers on fossil energy consumption, consider the impact category depletion of abiotic resources – fossil fuels, but bear in mind that renewable electricity also has a cost. See Appendix B for more information on LCA's.

Preferred format answer: MJ total energy / kg product,

What are the working conditions in all steps of your FMP?
CO_2 to feedstock

How does your FMP score for example on human rights and fair pay? Social and sociological LCA, as well as Safe by design provide useful tools to cover this.

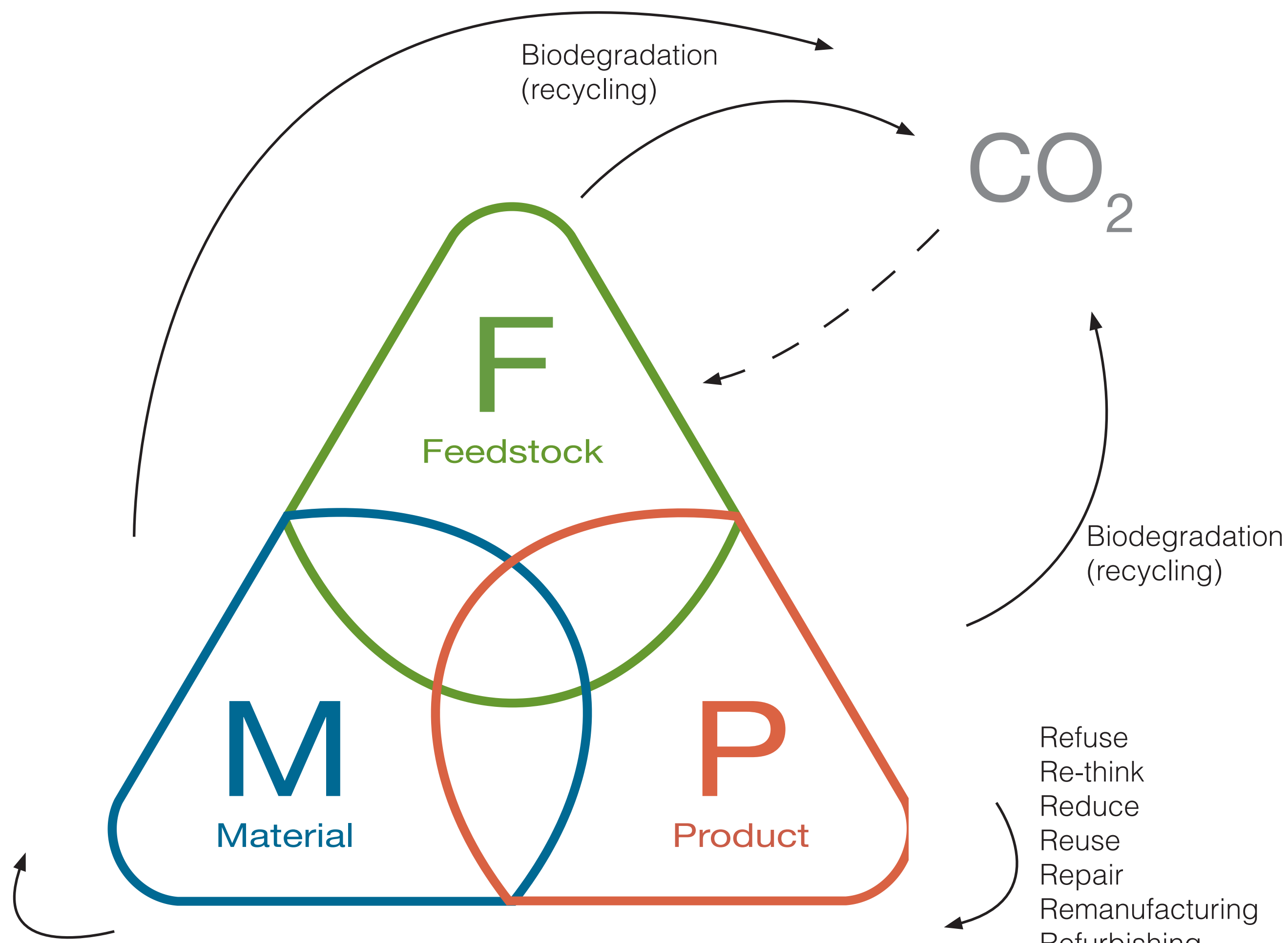
Preferred format answer: working conditions + argumentation

Appendix A - Design for a Circular Society, the R-ladder and FMP

Design for a Circular Society
The goal of Design for a Circular Society is to apply circularity principles in the design process. The circular economy approach aims to keep materials in use much longer and eventually return materials for new use. The core principle is that waste must be minimized. More information can be found via, for example, this MOOC.

The R-ladder
The circularity ladder, or the R-ladder, hierarchal arranges circularity strategies. The R-ladder is often used in the Dutch context to map and rank different circular strategies. There are various variants of the R-ladder, but in general the following structure is used.

		strategy	*example in circular bioeconomy*
Narrowing the Loop	R0	Refuse	Using publicly owned water fountains instead of a bioplastic water bottle
	R1	Rethink	Using a washable coffee mug instead of a disposable bioplastic cup
	R2	Reduce	Making biobased packaging smaller to save materials, and save space in delivery vans
Slowing the Loop	R3	Reuse	Designing the attachment of biobased façade panels in such a way they can be reused on another building
	R4	Repair	Keeping spare arm rests for a wooden chair in stock
	R5	Remanufacturing	Disassembling a wooden table, replacing damaged parts and reassembling
	R6	Refurbish	Making a multi-colour biobased carpet from left-over pieces of carpet
	R7	Repurpose	Making furniture from left-over wood from a building site



R-strategies and FMP
The Narrowing the Loop strategies – Refuse, Rethink and Reduce – and the Slowing the Loop strategies - Reuse Repair, Remanufacturing, Refurbish, Repurpose – mainly operate on the 'product' level, although for example 'Refurbishing' and 'Remanufacturing' touch upon the interface of material and product.

Recycling focusses on the material level and comprises several types of recycling.

- Mechanical recycling typically consists of cleaning, mechanical shredding, and reconstructing your material. For bioplastics this reconstructing can be done by melting and remoulding. In general this leads to quality losses of the material and is hence a form of 'downcycling'.
- Chemical recycling consists of chemical depolymerization of the material, followed by repolymerization in new materials. This generally preserves the material quality.
- Biological recycling can be used to break down a polymer in monomers, and is hence a nature based alternative to chemical recycling. Biological recycling is however still in its infancy.

A special type of recycling is biodegradation, in which either the feedstock, material or product is biologically broken down to CO_2.

Appendix B - Life Cycle Analysis, Eco-cost, True Pricing and FMP

LCA's and impact categories
The goal of an Life Cycle Analysis (LCA) is to evaluate the environmental impacts associated with all stages of a product's life cycle. To do so, all steps needed from feedstock to final disposal of a product are mapped, and the resources needed and waste generated per step is calculated.

This provides insight in the process-steps that have most impact, and allows to aggregate the impacts of the individual steps in one overall number. This number can be presented in several quantities (with corresponding units). If the CO_2-equivalents of all process steps are known, the sum of the impacts will provide information on the 'Global Warming Potential' of the LCA.

Other so-called 'impact categories' include for example 'ozone depletion potential' with unit 'CFC-equivalents', 'acidification potential' with unit 'SO_2 equivalents' and 'Eutrophication Potential' with units 'PO_4 equivalents'.

A disadvantage is that for an LCA a lot of detailed information is needed. Conducting an LCA is therefore not a logical step in the initial phase of biobased product design.

More information on LCA's can be found here.

Eco-cost and True Pricing
A possible next step is to put a monetary value on all impacts of the LCA.

For example, if a biobased chair produces 10 kg CO_2 / chair, and 1 kg PO_4 / chair, and if it costs 10 euro to remove 1 kg CO_2 from the atmosphere, and 5 euro to remove 1 kg PO_4 from the water, this translates to a so-called eco-cost value of :10 kg CO_2 / chair * 1 euro / kg CO_2 + 1 kg PO_4 / chair * 5 euro / kg PO_4 = 15 euro / chair.
This so-called 'eco-cost' hence presents a single monetary value representing the cost to prevent or offset the damage of the product.

The eco-cost approach provide valuable insights, but is limited to the impact categories of the LCA. Social factors, such as wages for laborers growing a biobased feedstock, are not taken in account into eco-cost calculations. T

rue pricing aims to include these social aspects, next to the environmental aspects covered under an eco-cost approach.

More information on Eco-cost (here) and true pricing (here).

Link to FMP
The FMP-approach aims to facilitate decision making in biobased product design. The focus from feedstock through material to product is generally in line with the borders set in a LCA-approach. The main impact categories, eco-cost/true pricing and social aspects, can be found as questions on the FMP-level.