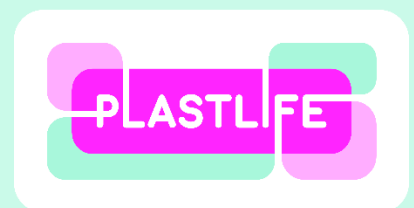


PlastLIFE D6.7 Techno-Economic Assessment (TEA) Report of New Materials

Raportti uusien materiaalien teknistaloudellisesta arvioinnista (TEA)

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Cover: Paperboard sheets manufactured in laboratory: reference material sheets (white, containing bleached softwood kraft pulp) and sheets containing both bleached softwood kraft fibres and fibres derived from horticultural side-streams (tomato and hop stalks). Cover photo by Jarkko Mikkonen.

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Abstract

Techno-Economic Assessment (TEA) Report of New Materials

This report discusses the techno-economic aspects of product prototypes. The prototypes were manufactured as a part of PlastLIFE project (WP 6, task 6.3):

- Paperboard for packaging, which contains fibres from greenhouse biomasses (tomato, cucumber stalks)
- Fibre-based liquid mulch
- Fish gelatine films
- Mycelium composite

Mostly the prototypes are aimed for replacing fossil-based packaging materials. The depth of the techno-economic assessment of the different prototypes varies.

Packaging board: Greenhouse fibres (tomato, cucumber) replace 16.7–20% of wood fibres with no significant loss in strength; tomato stalk fibres give better results than cucumber stalk fibres; industrial cost estimated 1 220–1 360 €/t of board.

Fibre liquid mulch (FLM): 100% bio-based and biodegradable; cost 1.11 €/m², labour and materials dominate costs; competitive against biodegradable mulches.

Fish gelatine film: Technically promising (casting, extrusion, pressing, coating); bioactivity enhanced by bark and berry side-stream extracts; limitations for food contact; economics not yet disclosed.

Mycelium composite: Potential replacement for Styrofoam and plastics; drying dominates energy use; economic feasibility depends on scaling efficiency.

In conclusions it can be stated that all materials create opportunities for reducing utilization of fossil plastics; main challenges for further development involve cost efficiency and industrial-scale process optimization.

Keywords: Techno-economic assessment, TEA, paperboard, greenhouse biomass, side-stream, mulch, mycelium, fish gelatine

Tiivistelmä

Raportti uusien materiaalien teknistaloudellisesta arvioinnista (TEA)

Tässä raportissa käsitellään tuoteprototyyppien teknistaloudellista arviointia. Tuoteprototyypit valmistettiin osana PlastLIFE-projektia (TP 6.3):

- Pakkauskartonki, joka sisältää kasvihuonebiomassasta valmistettuja kasvikuituja (tomaatin ja kurkun varret)
- Nestemäinen kate
- Kalagelatiinikalvo
- Myseelikomposiitti

Suurin osa prototyypeistä on tarkoitettu korvaamaan fossiiliperäisestä muovista valmistettuja pakkausmateriaaleja. Teknistaloudellisen arvioinnin yksityiskohtaisuus vaihtelee prototyyppien välillä.

Pakkauskartonki: Kasvihuonebiomassan kuidut (tomaatti, kurkku) korvaavat 16,7–20 % puukuidusta ilman merkittäviä heikennyksiä kartongin lujuusominaisuuksissa; tomaatinvarsien kuitu kurkunvarsikuitua parempaa; teollinen kustannustaso 1 220–1 360 €/t kartonkia.

Nestemäinen kate (FLM): 100 % biopohjainen ja biohajoava kateaine; kustannukset 1,11 €/m², suurimmat kulut työvoimasta ja materiaaleista; kilpailukykyinen biohajoaviin vaihtoehtoihin verrattuna.

Kalagelatiinikalvo: Teknisesti lupaava (valaminen, ekstruusio, puristus, päällystys), puunkuori- ja marjasivuvirtauutteiden tuoma bioaktiivisuus parantaa ominaisuuksia; rajoitteita elintarvikekäytössä, taloudelliset tiedot vielä arvioimatta.

Myseelikomposiitti: Korvaa styroksia ja muoveja; tuotanto sisältää kuivausvaiheen, joka kuluttaa eniten energiaa; taloudellista arviointia rajoittavat skaalauksen haasteet.

Yhteenvedona voidaan todeta, että kaikki ratkaisut ovat teknisesti toteuttamiskelpoisia ja luovat mahdollisuuksia fossiilisten muovien käytön vähentämiseen, mutta skaalauksen ja kustannusten optimointi on keskeistä jatkokehityksen kannalta.

Asiasanat: Teknistaloudellinen arviointi, TEA, kartonki, kasvihuonebiomassa, sivuvirta, katemateriaali, mycelium, kalagelatiini

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1 Introduction

This is a report in which techno-economic aspects of product prototypes are given. The prototypes were manufactured as a part of PlastLIFE project (WP 6, task 6.3). The prototypes covered are:

- Paperboard for packaging, in which part of the virgin wood-derived chemical fibres are substituted with fibres from greenhouse biomasses, namely tomato and cucumber stalks
- 100% biobased and biodegradable fibre liquid mulch (FLM)
- Fish gelatine films with enhanced bioactivity through addition of plant-based extracts
- Mycelium composite for packaging and construction

The aim of the prototype testing was to find out if it was possible to replace fossil-based products with these innovations. Mostly the emphasis was on packaging products. In this report, aspects of the prototypes' technical and economic feasibility are presented. The objective of the assessment was to communicate the results in addition to the wider audience, also to the developers of the prototypes; namely, the product development is still ongoing. For this reason, as well as for IPR issues, the depth of the information available for the different prototypes varies.

2 Packaging board containing fibres from greenhouse biomass

Packaging board samples were prepared in two occasions:

1. Laboratory-scale handsheets in a sheet former (180 g/m²): 100% bleached softwood kraft pulp (reference), replacing 20% of kraft fibres with fibres from tomato stalks, as well as replacing 20% of kraft fibres with fibres from hop stalks
2. Pilot-scale board rolls (185 g/m²) with a paper machine (Millvision, the Netherlands): 100% bleached softwood and hardwood kraft pulp (50:50, reference), replacing 16.7% of kraft fibres with fibres from tomato stalks, as well as replacing 16.7% of kraft fibres with fibres from cucumber stalks

The objective was to make a 100% bio-based and biodegradable packaging material, where forest-based fibres are partially replaced by fibres from horticulture-based side-stream. On both occasions (laboratory and pilot), the horticultural fibres were prepared by treating the original plant material with alkali (NaOH) followed by mechanical grinding. No bleaching was applied, as the horticultural fibres were intended to be also a visual element of the paper board. Calendering for smoothening the paper-board surface was applied to part of the samples. Mechanical properties testing was carried out to the paper board samples (both laboratory and pilot scale; results presented in detail in a separate report).

To evaluate the technical and economic feasibility, calculations were carried out for the pilot-scale manufacture of the paper board. Preliminary outlook for upscaling the production to industrial scale is also presented.

2.1 Paperboard manufacture in pilot scale

The process scheme for manufacturing the paperboard in pilot-scale is presented in Fig. 1.

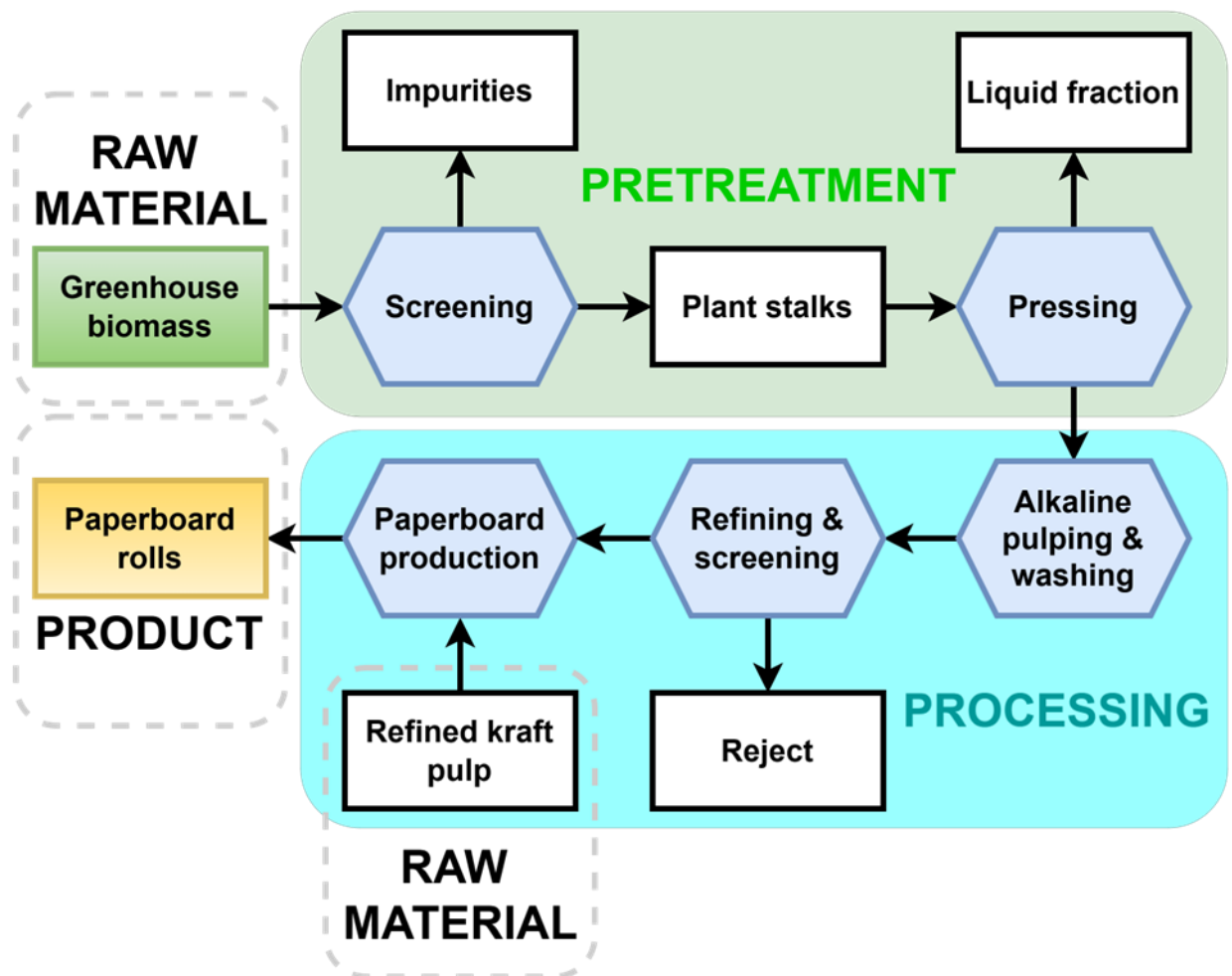


Fig. 1. Process scheme for manufacturing the paperboard in pilot scale. Three types of paperboard samples were manufactured: the reference sample containing only bleached kraft fibre (mix of softwood and hardwood), paperboard containing tomato stalk fibres, and paperboard containing cucumber stalk fibres. Further details are given in the text.

The paperboard manufacturing started with preparing the greenhouse biomass fibres (from cucumber and tomato, no bleaching). The furnish was prepared by mixing bleached kraft pulp fibres (50% softwood, 50% hardwood) and the greenhouse biomass fibres. The reference sample contained only kraft fibre, while two other samples contained one part of greenhouse biomass fibres and five parts wood kraft fibres (16.7% and 83.3%, respectively).

Basis weight (grammage) of the paperboard was 185 g/m². The energy consumption of the different process steps is based on the reported results from the pilot-scale board manufacturer (Millvision, The Netherlands), as well as many online resources (for further details, please contact the author).

2.1.1 Material and energy balances

Reference sample contained 100% bleached kraft pulp (50% softwood and 50% hardwood). Total amount produced was 6 kg. The results for the balance calculation are presented in Table 1.

Table 1. Balance for manufacturing 6 kg paperboard roll from virgin wood pulp (bd=bone dry, meaning absolute dryness, i.e. 0% moisture)

	Amount	Unit	Energy/unit	Total energy	Unit	% of total
Pumping	1 000.00	kg furnish	0.0009	0.90	kWh	2.42 %
Refining	6.00	bdkg	0.80	4.80	kWh	12.90 %
Pulping	6.00	bdkg	0.25	1.50	kWh	4.03 %
Paper machine	6.00	bdkg	5.00	30.00	kWh	80.65 %
TOTAL				37.20	kWh	100.00 %

Total H₂O consumed 1 015 kg (~170 kg/bdkg of board); energy 6.2 kWh/bdkg board.

Tomato fibre board contained 16.7% tomato fibre, the rest was kraft pulp (total amount 6 kg of paperboard). Fibre yield from tomato stalks was 85%, NaOH charge 5.0%. In the manufacture, HCl was used for neutralization. The results for the balance calculation are presented in Table 2.

Table 2. Balance for manufacturing 6 kg paperboard roll containing tomato fibre (bd=bone dry, meaning absolute dryness, i.e. 0% moisture)

Tomato fibre board	Amount	Unit	Energy/unit	Total energy	Unit	% of total
Pressing	3.43	kg fresh	0.02	0.07	kWh	0.17 %
Heating	24.76	kg suspension	0.0814	2.01	kWh	4.95 %
Digestion	24.76	kg suspension	0.0041	0.10	kWh	0.25 %
Pumping	1 047.06	kg H ₂ O	0.0011	1.13	kWh	2.76 %
<i>To washing</i>	<i>47.06</i>	<i>kg H₂O</i>	<i>0.0048</i>	<i>0.23</i>	<i>kWh</i>	<i>0.55 %</i>
<i>To the board machine</i>	<i>1 000</i>	<i>kg furnish</i>	<i>0.0009</i>	<i>0.90</i>	<i>kWh</i>	<i>2.21 %</i>
Refining	6.00	bdkg	0.80	4.80	kWh	11.78 %
Pulping	6.00	bdkg	0.25	1.50	kWh	3.68 %
Paper machine	6.00	bdkg	5.00	30.00	kWh	73.65 %
TOTAL				40.81	kWh	100.00 %

Total H₂O consumed 1 088 kg (~181 kg/bdkg of board); energy 6.8 kWh/bdkg board.

Cucumber fibre board contained 16.7% cucumber fibre, the rest was kraft pulp (total amount 6 kg of paperboard). Fibre yield from tomato stalks was 80%, NaOH charge 5.0%. In the manufacture, HCl was used for neutralization. The results for the balance calculation are presented in Table 3.

Table 3. Balance for manufacturing 6 kg paperboard roll containing cucumber fibre (bd=bone dry, meaning absolute dryness, i.e. 0% moisture)

Cucumber fibre board	Amount	Unit	Energy/unit	Total energy	Unit	% of total
Pressing	7.72	kg fresh	0.02	0.14	kWh	0.34 %
Heating	26.31	kg suspension	0.0814	2.14	kWh	5.23 %
Digestion	26.31	kg suspension	0.0041	0.11	kWh	0.26 %
Pumping	1 050.00	kg H ₂ O	0.0011	1.13	kWh	2.75 %
<i>To washing</i>	<i>50.00</i>	<i>kg H₂O</i>	<i>0.0045</i>	<i>0.23</i>	<i>kWh</i>	<i>0.55 %</i>
<i>To the board machine</i>	<i>1 000</i>	<i>kg furnish</i>	<i>0.0009</i>	<i>0.90</i>	<i>kWh</i>	<i>2.20 %</i>
Refining	6.00	bdkg	0.80	4.80	kWh	11.73 %
Pulping	6.00	bdkg	0.25	1.50	kWh	3.66 %
Paper machine	6.00	Bdkg	5.00	30.00	kWh	73.28 %
TOTAL				40.95	kWh	100.00 %

Total H₂O consumed 1 091 kg (~182 kg/bdkg of board); energy 6.8 kWh/bdkg board.

2.1.2 Economy: pilot scale

The assumed prices for bleached softwood (SW) and hardwood (HW) kraft pulps were 650 €/adt and 500 €/adt, respectively (adt=air dry tonne, meaning pulp at 90% dry matter content, DMC). The electricity price was estimated to be 0.25 €/kWh, whereas the labour costs were calculated for two researchers, who were running the pilot machine (estimated hourly salary 45.00 €). The pilot-scale board machine's production speed is 1 m/min, which is very slow compared to industrial machines.

Reference sample contained 50% SW and 50% HW kraft pulp. The production time was assumed to be 1 working day for two persons. 20% additional costs were assumed for the production, this is allocated for shipping, minor materials, *etc.* (see Table 4).

Table 4. Economy for manufacturing 6 kg paperboard roll from virgin wood pulp in pilot scale (bd=bone dry, meaning absolute dryness, i.e. 0% moisture; ad=air dry, i.e. containing 10% moisture)

Item	Cost, €/Unit	Unit	Amount	Unit	Total
Kraft pulp	0.575	€/adkg	6.67	adkg	3.83 €
Electricity	0.25	€/kWh	37.20	kWh	9.30 €
Labour cost	45.00	€/h	14.5	h	652.50 €
Other costs	9.17	€/board roll	1	board roll	9.17 €
TOTAL					674.80 €
TOTAL/bdkg					112.47 €

Tomato fibre board contained 16.7% tomato fibre, the rest was kraft pulp (total amount 6 kg of paperboard). The results for the economy are presented in Table 5. 20% additional costs were assumed for the production, this is allocated for chemicals, shipping, minor materials, *etc.* The production time was estimated to be 1.5 days (two persons working full time), which is more compared with the reference sample. This is justified due to the time, which needs to be allocated for manufacturing the fibre material from the tomato stalks.

Table 5. Economy for pilot-scale manufacturing of 6 kg paperboard roll containing tomato fibre and virgin wood pulp (bd=bone dry, meaning absolute dryness, *i.e.* 0% moisture; ad=air dry, *i.e.* containing 10% moisture)

Item	Cost, €/Unit	Unit	Amount	Unit	Total
Kraft pulp	0.575	€/adkg	5.56	adkg	3.19 €
Tomato pulp	0.431	€/adkg	1.11	adkg	0.48 €
Electricity	0.25	€/kWh	40.81	kWh	10.20 €
Labour cost	45.00	€/h	21.75	h	978.75 €
Other costs	9.25	€/board roll	1	board roll	9.25 €
TOTAL					1 001.88 €
TOTAL/bdkg					166.98 €

Cucumber fibre board contained 16.7% cucumber fibre, the rest was kraft pulp (total amount 6 kg of paperboard). For pilot-scale production economy, see Table 6. 20% additional costs were assumed for the production, this is allocated for chemicals, shipping, minor materials, *etc.* The production time was estimated to be 1.5 days (two persons working full time), which is more compared with the reference sample. This is justified due to the time, which needs to be allocated for manufacturing the fibre material from the cucumber stalks.

Table 6. Economy for pilot-scale manufacturing of 6 kg paperboard roll containing cucumber fibre and virgin wood pulp (bd=bone dry, meaning absolute dryness, *i.e.* 0% moisture; ad=air dry, *i.e.* containing 10% moisture)

Item	Cost, €/Unit	Unit	Amount	Unit	Total
Kraft pulp	0.575	€/adkg	5.56	adkg	3.19 €
Cucumber pulp	0.479	€/adkg	1.11	adkg	0.53 €
Electricity	0.25	€/kWh	40.95	kWh	10.24 €
Labour cost	45.00	€/h	21.75	h	978.75 €
Other costs	9.26	€/board roll	1	board roll	9.26 €
TOTAL					1 001.98 €
TOTAL/bdkg					167.00 €

2.2 Paperboard manufacture: outlook for upscaling

Based on the pilot-scale experiments TEA results, an outlook for industrial-scale manufacturing of tomato and cucumber fibres was produced. The approach for the calculations was simple: it was assumed that the raw materials account for 50% of the total manufacturing costs, while energy accounts for 20%, labour cost for 20%, and other costs (*e.g.* logistics) account for 10% of the total manufacturing costs. The kraft pulp prices are identical with the earlier pilot-scale estimations: SW pulp 650 €/adt and HW pulp 500 €/adt. These estimations are based on online sources, please contact the author for details.

2.2.1 Economy: outlook for industrial scale

Reference case, *i.e.* paperboard containing 50% SW and 50% HW bleached kraft pulp is presented in Table 7. The costs are estimated for one tonne (1 000 kg) of paperboard.

Table 7. Economy of manufacturing one tonne (1 000 kg) paperboard from bleached kraft pulp in industrial scale.

Item	Cost, €/Unit	Unit	Amount	Unit	Total
Kraft pulp	638.89	€/bdt	1.00	bdt	638.89 €
Energy (steam & electricity)					255.56 €
Labour cost					255.56 €
Other costs					127.78 €
TOTAL					1 277.78 €

Tomato fibre board case is presented in Table 8. The costs are estimated for one tonne (1 000 kg) of paperboard.

Table 8. Economy of manufacturing one tonne (1 000 kg) paperboard from bleached kraft pulp and tomato stalk fibres in industrial scale.

Item	Cost, €/Unit	Unit	Amount	Unit	Total
Kraft pulp	638.89	€/bdt	0.83	bdt	532.41 €
Tomato pulp	479.17	€/bdt	0.17	bdt	79.86 €
Energy (steam & electricity)					244.91 €
Labour cost					244.91 €
Other costs					122.45 €
TOTAL/bdt					1 224.54 €

In the scenario presented above, the tomato fibre is assumed to be economical (75% price of kraft fibre); in another scenario (125% price), total costs are 1 331.02 €/bdt. Estimating the correct price for the tomato fibres is challenging because industrial-scale production for these materials does not exist currently.

Cucumber fibre board case is presented in Table 9. The costs are estimated for one tonne (1 000 kg) of paperboard.

Table 9. Economy of manufacturing one tonne (1 000 kg) paperboard from bleached kraft pulp and cucumber stalk fibres in industrial scale.

Item	Cost, €/Unit	Unit	Amount	Unit	Total
Kraft pulp	638.89	€/bdt	0.83	bdt	532.41 €
Cucumber pulp	532.41	€/bdt	0.17	bdt	88.73 €
Energy (steam & electricity)					248.46 €
Labour cost					248.46 €
Other costs					124.23 €
TOTAL/bdt					1 242.28 €

In the scenario presented above, the cucumber fibre is assumed to be economical (75% price of kraft fibre); in a scenario, where the price is assumed higher (125% price of kraft pulp), total costs are 1 331.02 €/bdt. Estimating the correct price for the cucumber fibres is challenging because industrial-scale production for these materials does not exist currently.

2.2.2 Raw material potential in Finland

During tomato and cucumber production, stalk is produced as a side-stream. When the approximate ratio of the crop to fresh stalk is known, the theoretical capacity of stalk-based fibre production in Finland can be calculated. Geographically, most of the greenhouse tomato and cucumber production in Finland takes place in Ostrobothnia (especially in Närpiö).

Hooks and strings, typically made of plastic, are used to support the tomato and cucumber plants in greenhouses. Removing the non-biobased material is challenging and this hinders the applicability of the stalk material (see Suojala-Ahlfors, T. 2020, p. 21, in Finnish).

Table 10. Raw material potential for tomato and cucumber fibre production in Finland.

	Tomato	Cucumber	Unit
Crop ^a	41 000	54 000	t/a
Fresh crop : fresh stalk ratio ^b	10.4:1	10.4:1	-
Fresh stalk amount	3 942	5 192	t/a
Fibre yield from fresh stalk ^c	0.29	0.14	bdt/t
Fibre potential in Finland	1 149	748	bdt/a
Fibre potential in Finland	1 277	831	adt/a
Board potential (containing 16.7% greenhouse fibres)	6 881	4 477	bdt/a

^aLuke's Information Service, 2025

^bThe figure applied from Suojala-Ahlfors, T., 2020 (p. 22, in Finnish), originally given for tomato grown at Lepaa, Finland; here also used in calculation for cucumber stalk material

^cFrom material balance constructed for this report

2.3 Conclusions: packaging board containing tomato and cucumber fibre

Producing 100% biobased and biodegradable board containing side-stream fibres from greenhouse biomass is technically possible. Replacing 17-20 w.% of the wood fibres with greenhouse biomass-based fibres gives the board nice appearance and has not a significant effect on the mechanical properties of the paperboard (this topic is covered in detail in another PlastLIFE project report). However, the availability of the material is limited, thus enabling manufacture of specialty product: based on calculations presented in this report, the theoretical maximum of annual production in Finland is only ~7 000 tonnes of paperboard containing tomato fibre (almost 4 500 tonnes for cucumber fibre, respectively). The total production of paperboard in Finland in 2024 was 3.7 million tonnes. (Metsäteollisuus ry. 2025)

Based on literature and on the laboratory and pilot scale experiments, the estimated price for the board produced industrially is 1 220-1 360 €/bdt. Fossil-based plastics cost 800-1 400 €/t (see Hieminga et al. 2024). Even though these are preliminary figures, in which no investment costs are considered (e.g. for the production equipment), they show that this type of packaging material might well be feasible economically.

For upscaling the production, there are some technical challenges, however:

- Removing the inorganic impurities (e.g. plastic strings and hooks used for support) from the greenhouse biomass
- Industrial processes optimised for very large production volumes → what is the best approach for utilising greenhouse biomass?

- Utilising the tomato and cucumber fibres in industrial board machines must be tested and the process optimised
- Scaling up the process needs resources: research on pulping and papermaking processes, as well as investment on the required equipment

3 Liquid mulch manufactured from 100% bio-based sustainable materials

Mulch is a material used for covering soil principally to prevent weed growth. Currently, plastic film mulch is used widely. The sustainability of these materials is questioned: they are fossil-based and non-biodegradable; moreover, after use they should be removed and disposed.

To overcome the challenges, bio-based biodegradable mulches (films, paper) have been developed (Salonen *et al.* 2017). In this context, a new liquid mulch material based on industrial side-streams (cellulosic fibres and pyrolysis liquid) was recently patented in Finland by researchers from Natural Resources Institute Finland (Luke) (Rasa and Hagner 2024). A scheme for the manufacturing process of the fibre-based liquid mulch (FLM) from industrial side-streams is presented in Fig. 2, and a brief techno-economic assessment of FLM application will be discussed in this chapter.

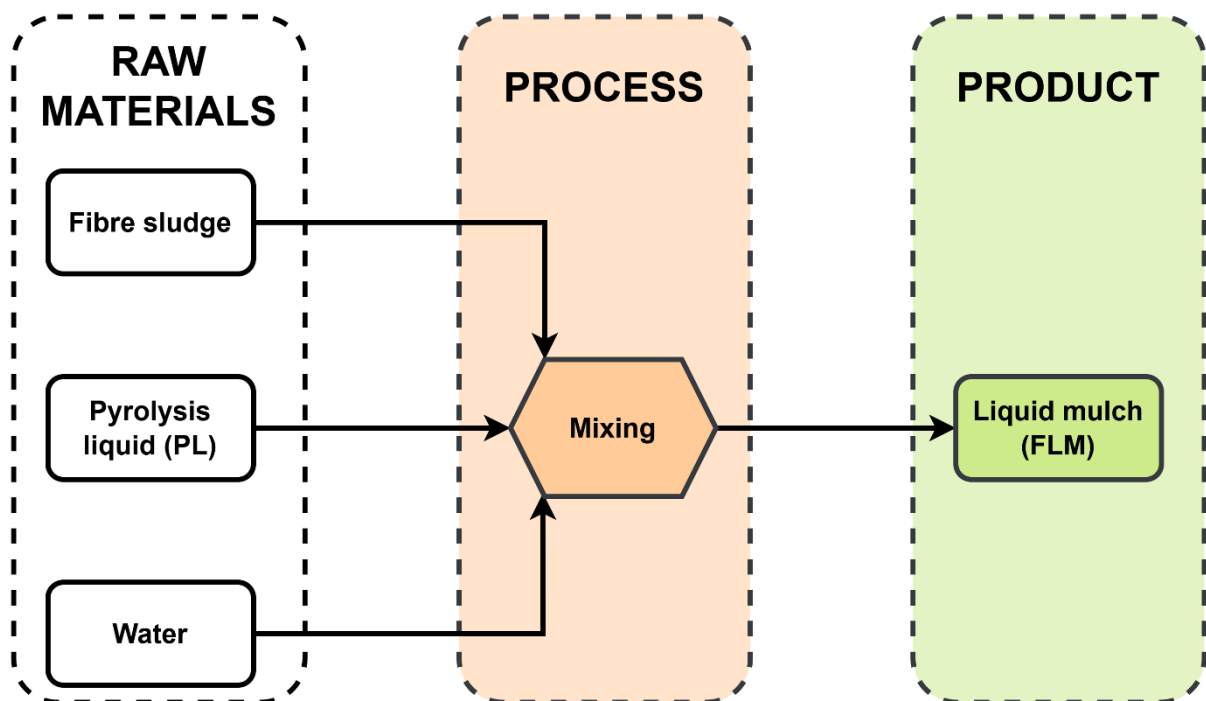


Fig. 2. Cellulose fibres, pyrolysis liquid (PL) and water are mixed to form a fibre-based liquid mulch suspension (FLM).

3.1 FLM recipe: suspension to be spread on 500 m² area

In this example, we consider producing a batch of FLM (fibre-based liquid mulch) for covering a field area of 500 m². The recipe for the production is presented in Fig. 3.

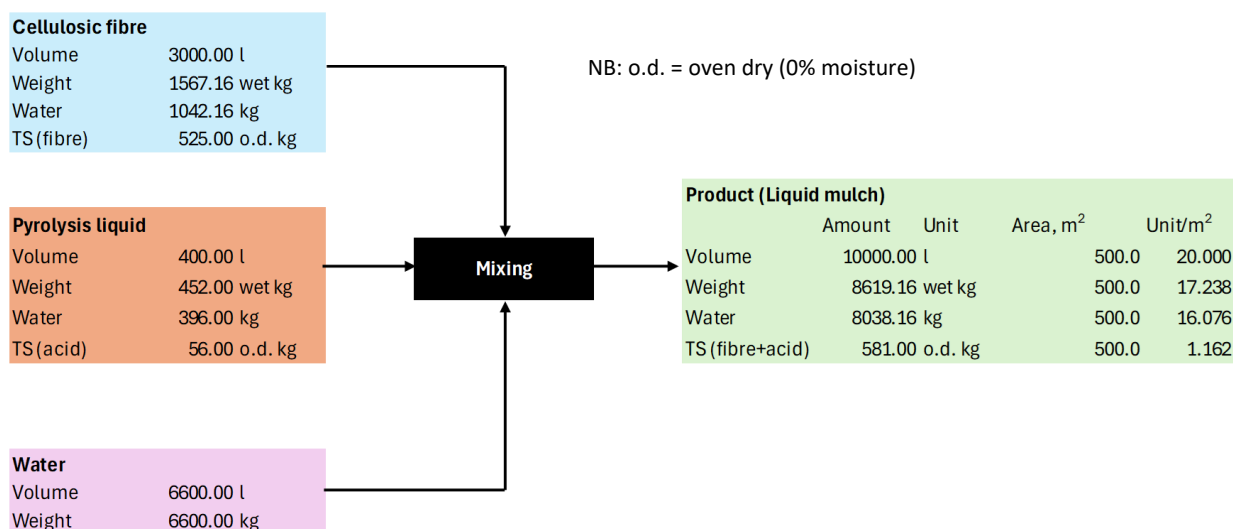


Fig. 3. Recipe for producing FLM (fibre-based liquid mulch) for covering a field area of 500 m². The FLM is manufactured of bio-based industrial side-streams (cellulosic fibre and pyrolysis liquid) mixed with water, making the product completely biodegradable.

3.2 FLM economy

3.2.1 Materials and transport

Costs of materials for manufacturing the FLM batch, including transport, are presented Table 11.

Table 11. Costs for manufacturing FLM batch to be spread on 500 m² (total volume 10 m³).

	Material cost (€/m ³)	Volume (m ³)	Material cost	Transport cost (€/h)	Cargo (m ³)	Distance (return, km)	Time (h)	Total transport cost	Total cost
Fibre component	0.00 €	3.00	0.00 €	62.44 €	137.14	300	7.25	3.30 €	3.30 €
Pyrolysis liquid	300.00 €	0.40	120.00 €	62.44 €	18.29	300	7.25	9.90 €	129.90 €
Water	2.52 €	6.60	16.63 €	-	-	-	-	-	16.63 €
TOTAL	-	10.00	136.63 €	-	-	600.00	-	19.81 €	156.44 €

Literature references for the data provided upon request.

The fibre component is an industrial side-stream from paper and board manufacturing: a fibrous residual material, which is not incorporated as a part of paper or board during the process. Current industrial procedure is to combust this material, but its relatively high moisture level renders the energy content negligible; hence, it has no value and therefore its price is set to 0 €, meaning that its only cost results from the transport. In this example it is assumed that large quantities of fibre suspension and pyrolysis liquid (PL) can be stored near the FLM manufacturing site. It is further assumed that for minimising the costs, the procedure is to haul big loads of raw materials to cover e.g. one year's supply. The hauling distance for both PL and fibre suspension is 300 km (two separate one-day transports).

3.2.2 Manufacture and spreading

The FLM is manufactured at the farm to minimise the transport distance of the final product. The fibre suspension and PL are lifted with a tractor into a tank where water is added and the suspension is mixed with a pump. Spreading the FLM on the field is performed manually: FLM is transported to the site with a tractor. Spraying the FLM on the field is accomplished by pumping through a hose with a nozzle.

The manufacturing costs are presented in Table 12 and the costs of spreading the FLM are shown in Table 13. It is assumed that the FLM is spread on five 100 m² plots on the field (e.g. in a tree nursery).

Table 12. Manufacturing costs of the FLM batch.

	Amount (kg)	Volume (m ³)	Tractor (h)	Tractor cost (€/h)	Employee cost (€/h)	Pump rent (€/d)	Pump power (kW)	Electricity price (€/kWh)	Total cost of manufacture
FLM	8 619	10.00	5.00	5.00 €	25.46 €	25.00 €	0.90	0.11 €	177.80 €
			<i>Total:</i>	25.00 €	127.30 €	25.00 €		0.50 €	177.80 €

Literature references for the data provided upon request.

Table 13. Spreading costs of the FLM batch.

	Material amount (kg)	Volume (m ³)	Number of plots	Tractor cost (€/h)	Employee cost (€/h)	Pump power (kW)	Working time (h)	Total spreading cost
FLM	8 619	10.00	5	5.00 €	25.46 €	0.90	7.25	221.55 €
			<i>Total:</i>	36.25 €	184.59 €	0.72		221.55 €

Literature references for the data provided upon request.

3.2.2.1 Total costs

Total costs of the FLM produced for covering 500 m² are 555.78 €, which converts to 1.11 €/m². The largest expenses are accounted to manual labour and materials (55% and 24%, respectively). The FLM raw materials cost prediction is challenging because markets are not yet developed (e.g. PL cost are hard to predict).

Compared to existing weed control methods, the material and application costs for FLM are probably higher than the respective costs for polyethene film mulch. However, as FLM is completely biodegradable, there are no costs for removing the mulch, whereas these costs are apparent for the polyethene film mulch. The costs of FLM can be estimated to be comparable to other biodegradable mulches, but considerably cheaper than manual weeding.

Summaries of the cost categories are presented in Table 14 as absolute values in euros, whereas Fig. 4 shows the division in percentage.

Table 14. Total costs of FLM tabulated in different categories.

Costs as categories	
Manual labour	311.89 €
Materials	136.63 €
Equipment	87.46 €
Transport	19.81 €
Total	555.78 €

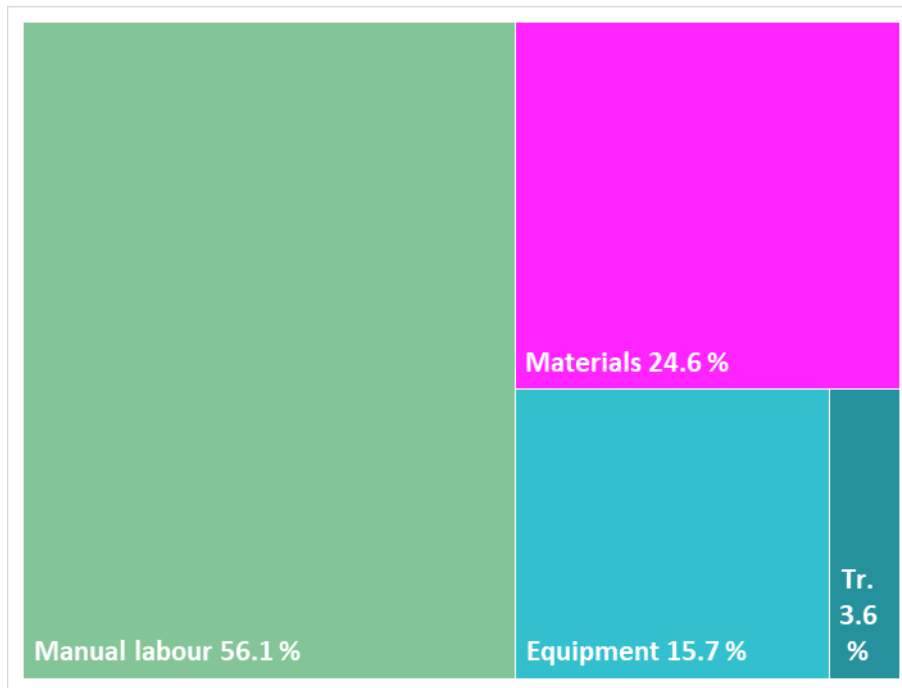


Fig. 4 Percentage division of the different cost categories for total costs of FLM (including manufacture, materials, and spreading). Tr.=transport.

3.3 Conclusions: fibre liquid mulch (FLM)

FLM is patented and proven to be effective in weed control. FLM is also biobased and completely biodegradable. On one hand, the easy biodegradability weakens FLM’s weed controlling ability. On the other this is also a benefit. Some mulch materials, which are claimed to be biodegradable, do not actually decompose in the Finnish nature, but remain in the soil and water bodies as microplastic particles (Finnish Environmental Institute 2025).

Non-biodegradable mulch materials need to be removed from the field, creating extra work and expenses compared to FLM. Moreover, FLM is easy to spread on any type and shape of field. The concept is not completely ready yet, and therefore through optimising the manufacturing and spreading of FLM, cost savings can be expected. One challenge relates to the raw materials of the FLM: as these are industrial side-streams, their characteristics are varied. Additionally, the markets for the raw materials are not developed, and optimisation will be needed in this aspect also.

4 Gelatine-based functional packaging film

Gelatine can be feasibly extracted in industrial scale from fish side-streams (Setälä *et al.* 2021). This material can be made into films. The feasibility of utilising these materials as packaging solutions was investigated and the results are briefed in this chapter.

4.1 Aspects of the feasibility of the gelatine-based functional packaging films

During PlastLIFE it has been proven that:

- + Gelatine films suitable for manufacturing packaging products can be casted; also extrusion, heat pressing, and coating paperboard with gelatine give promising results
- + Addition of Nordic tree bark and berry side-stream extracts render the casted films bioactive, giving the films antibacterial barrier properties
- + Tree bark extracts improve the mechanical strength of the gelatine films
- Due to dietary and/or medical reasons, fish-based gelatine should not be in direct contact with foods not containing fish
- Bark extract components are not allowed to be in direct contact with foods
- Casting is not a suitable industrial-scale film manufacturing method
- Biological activity of the packaging film decreases upon heating, which restricts the suitable large-scale manufacturing method for gelatine-based packaging films

Because the research is still ongoing and not complete, at this point economic considerations cannot be disclosed. Next step will be scaling up the manufacturing process of the gelatine films.

5 Mycelium composite for packaging products and insulation panels

Mycelium is the 'roots' of the fungi. Mycelium can be grown in sterile conditions to produce mycelium-based materials, *e.g.* composites or pure mycelium materials. Mycelium grows like a network connecting and binding lignocellulosic fibres.

The research into this prototype product aims to replacing Styrofoam, producing mycelium-based biofilms, and replacing plastic films. In this chapter, very brief outlook into development of this product is presented.

5.1 Mycelium composite production process

For producing the composite, side-streams from forestry and agricultural industry are used as raw materials. The production process includes fermentation and drying; most energy and time is spent during the drying process. Very small amounts of waste can be expected from the process. The performed tests have proven that the product is suitable for replacing Styrofoam in packaging and construction.

At this stage, economic consideration cannot be disclosed. The biggest challenge can be expected to be optimising the manufacturing time so that sufficient production volumes are ensured. Also, minimising energy consumption during thermal drying is necessary.

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