FiberLean
Strength by Design

Microfibrillated cellulose (MFC) products from FiberLean wet stirred media mills: Applications in specialty paper products

Presented by:

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Agenda

- Company Overview
- FiberLean MFC grinders
- Morphology of Grinder MFC
- Regulatory, end-of-life, ESG
- Grinder MFC in paper and board
- Case study examples
- Conclusions

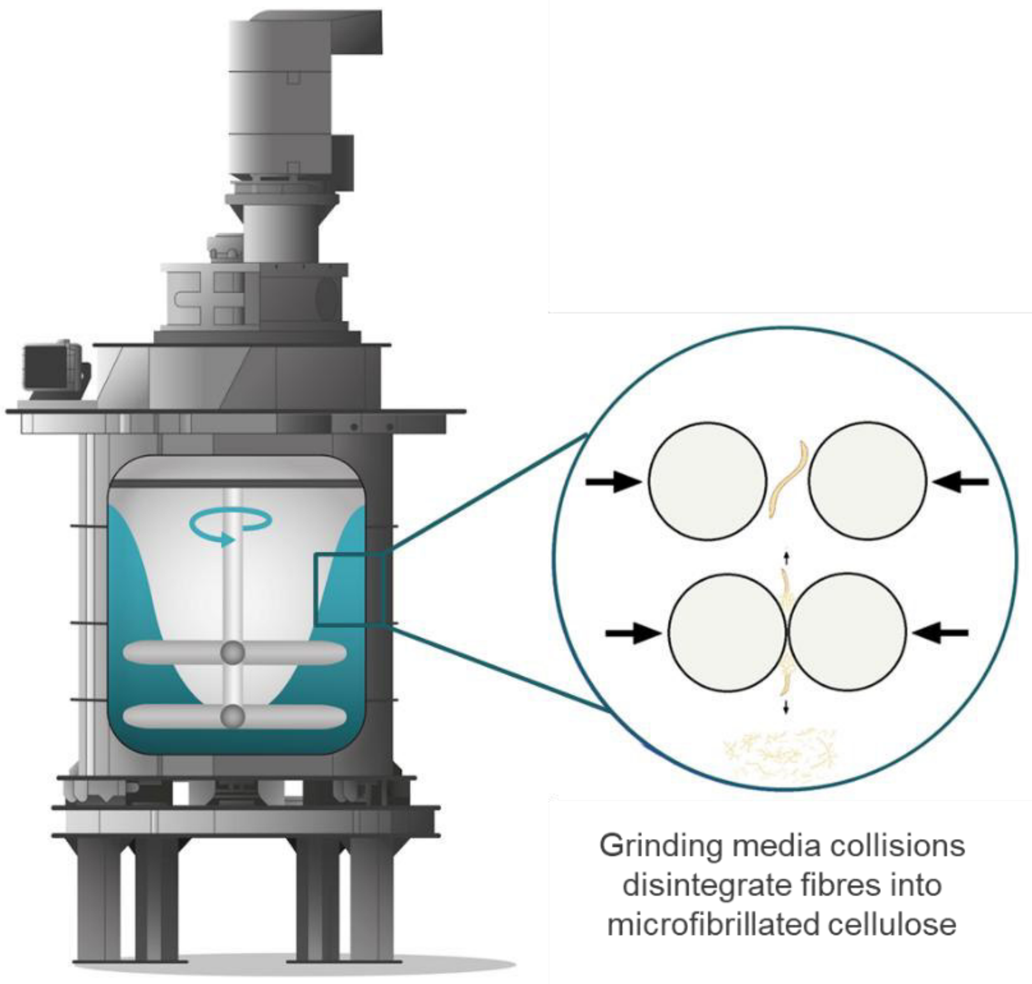
FiberLean company overview

Leading supplier of MFC equipment based on solid process knowledge

Leading independent MFC equipment supplier	Operating since 2016	World-class technical expertise in MFC technology and production
Operating industrial-scale MFC plant in Trebal, Cornwall	State-of-the-art industrial research and application laboratories	Capability to conduct onsite MFC trials worldwide
Experienced engineering and project implementation team	Leading research on MFC use and application with extensive patent portfolio	Equipment supply and fabrication partners

• FiberLean MFC Grinders (Vertical Wet Stirred Media Mill Grinders)

Modular ~1200 and ~400 dmtpa MFC modules



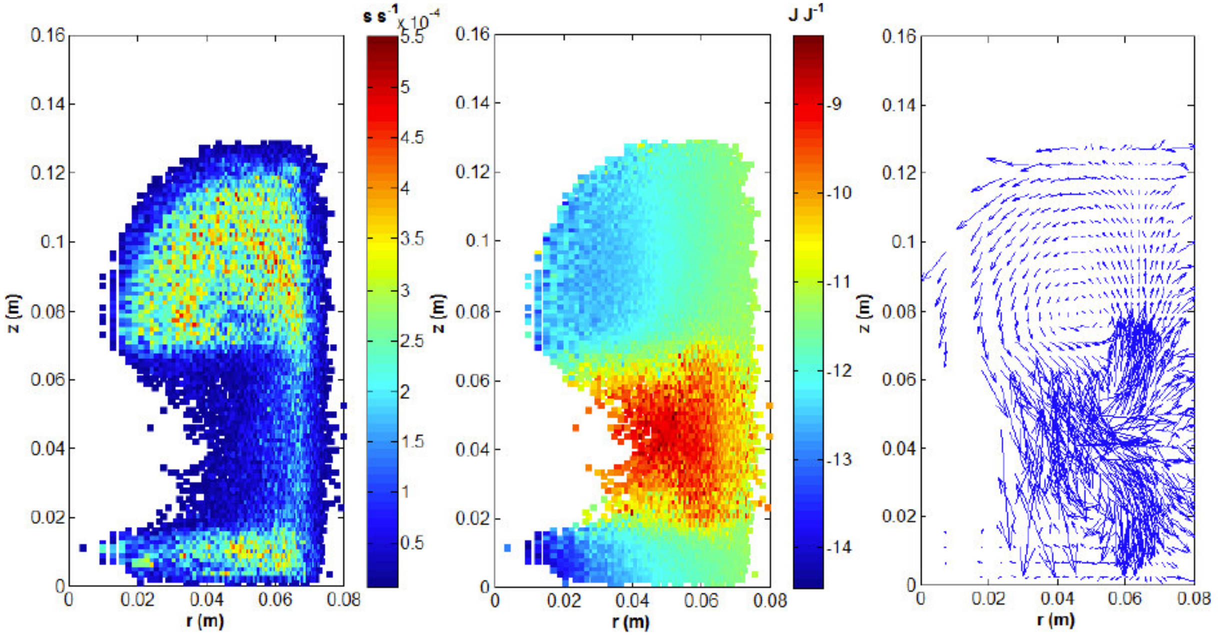
Grinding media collisions disintegrate fibres into microfibrillated cellulose

- Fortified stirred vessel, where collisions between grinding media beads break intervening particles.
- Widely used in minerals and mining industry, adapted by FiberLean to break and fibrillate fibres into MFC. Required modifying design, operating principles, and theory.
- Grinding media are the ‘working surfaces’ for fibrillation; very high active surface area that scales with vessel volume; permits high throughput and efficient production of MFC.
- Typically operated in continuous mode, where energy input is controlled with outlet flow rate and motor power.
- Robust, reliable, simple, cost-effective, energy efficient design.
- Mechanical, additive-free process.

FiberLean MFC Grinders Optimisation

- Effective MFC production requires ***high surface area generation whilst maintaining fibril aspect ratios***.

- Stirred mills have the key advantage that the ***strength of forces can be varied by many orders of magnitude with little to no equipment modification.***
  - Machine parameters – specific energy input, Impeller speed, Media fill fraction, Impeller geometry.
  - Grinding media parameters – density, elasticity, size, shape, surface roughness.
  - Feedstock parameters – fibre dimensions, fibre strength, fibre chemistry (hemicellulose, lignin), solids content.



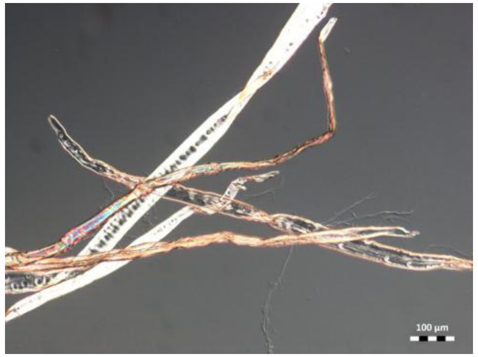
***PEPT tracking** of a lab-scale grinder – (left) occupancy, (middle) kinetic energy distribution, (right) velocity vectors.*

➡ ***High quality MFC can be produced from a wide range of feed fibres.***

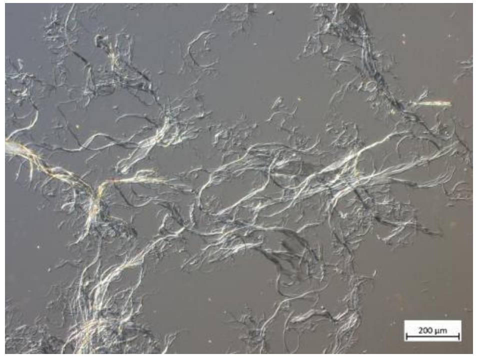
FiberLean MFC Grinders and MFC production plants

Morphology of Grinder-Produced MFC

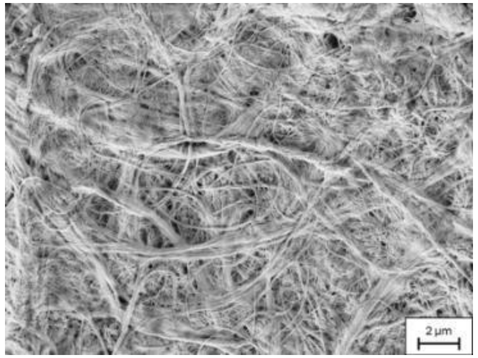
- Grinder-produced MFC is best described as 'surface-nanostructured macromaterial'.
- Micro and nano scale fibrillar surface structure anchored to a sub-millimetre scale macrostructure.
- Fine and long micro and nano fibrils in the nanostructure enhance bonding at fibre-fibre joints and with filler particles.
- A coarse macrostructure improves bridging between fibres and improves retention.
- The objective is to efficiently generate a high level of micro and nano fibrillation whilst retaining long fibrils and coarse macrostructure.



Unprocessed pulp



Optical micrograph showing MFC coarse macrostructure



SEM showing MFC fibrillar micro and nano structure

Grinder-Produced MFC: Regulatory, end-of-life, ESG

- BfR, FDA, Canadian and Chinese food contact paper clearance.
  - FDA FCN 002413, BfR Recommendations XXXVI, XXXVI/1, XXXVI/2 & XXXVI/3
- Not a nano-material according to US EPA and EU definitions.

EU Nano or not nano: An unbiased approach to classifying FiberLean microfibrillated cellulose, Hewson et al, Cellulose, (2024). *https://doi.org/10.1007/s10570-024-05980-z*

- No negative health effects found.
  - https://pmc.ncbi.nlm.nih.gov/articles/PMC6994281/
  - https://pmc.ncbi.nlm.nih.gov/articles/PMC7329166/
  - https://pmc.ncbi.nlm.nih.gov/articles/PMC6474143/
- MFC not a final product but we have carried out the following testing to confirm MFC has no negative impact on end of life:
  - Recyclability – PTS-RH 021:2012 – bleached and unbleached MFC coated papers passed.
  - Biodegradability – OECD 301B – MFC suspensions with and without biocide were biodegradable.
  - Compostability – ISO 14855 – bleached and unbleached MFC coated papers were biodegradable under industrial composting conditions.
- Allows lighter products, reducing transport related emissions.
- Supports recyclability and circular economy by enabling plastic replacement in packaging.

Using MFC as an additive in fibre-based products

(Paper, packaging, tissue, specialty paper and pulp products)

- Enhanced bonding within fibre-based structures
- Formation of closely packed, low porosity layers
- Wide regulatory clearance
- Recyclable, compostible, sustainably sourced

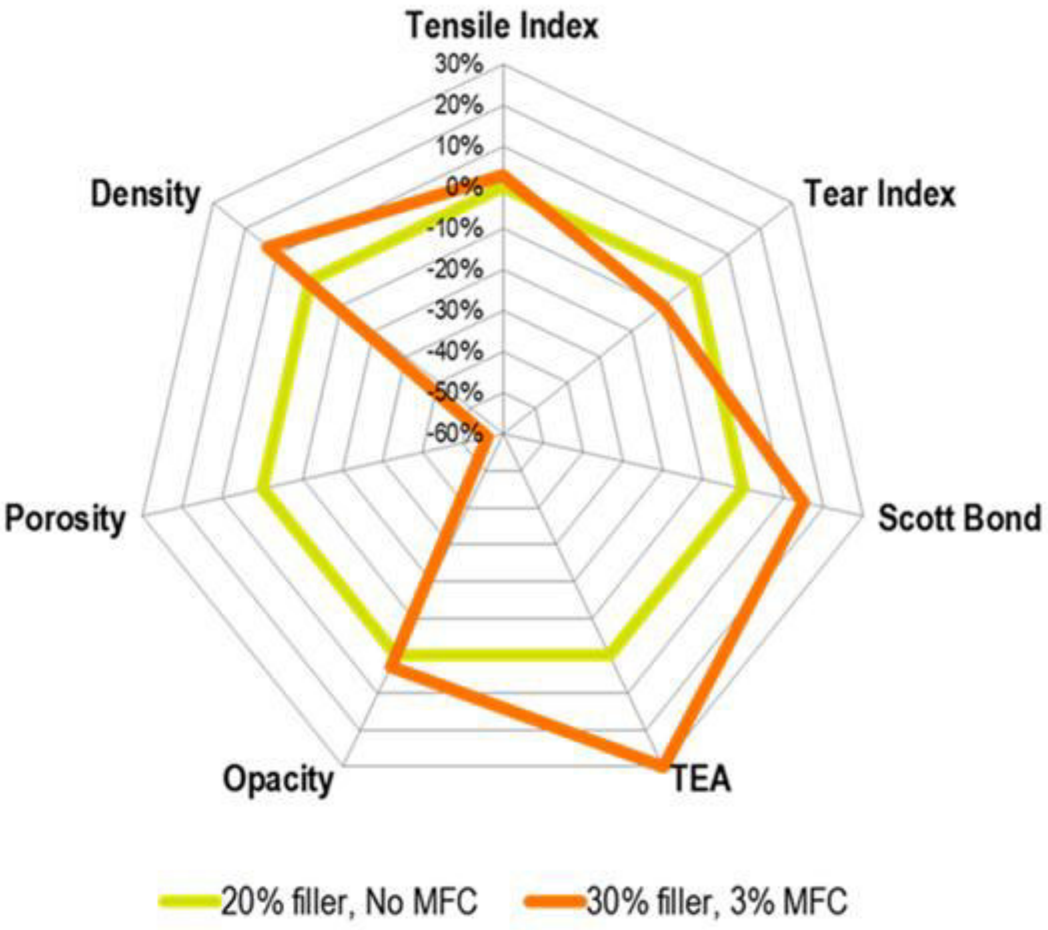
→

- Light weighting
- Reduce long fibre use
- Increase filler use
- Improve mechanical & elastic properties
- Improve coverage
- Barrier properties
- Improve environmental performance
- Improve runnability

Grinder-Produced MFC: Paper Performance

Typically, use of MFC in a web-based system is associated with:

- Improved performance stability.
- Increased initial wet web strength.
- Minimal impact on wet end chemistry.
- Improved dry mechanical properties.
- Improved opacity.
- Improved formation.
- A much tighter sheet (reduced porosity).
- Improved coating hold out.
- Improved smoothness.
- Loss of bulk and slower drainage are negatives but can be managed.



Applications of MFC in Paper & Packaging

FiberLean MFC is a tool enabling papermakers to push the boundaries and achieve more…

Improved Properties

- Increase web strength (wet & dry)
- Porosity control & coating hold-out
- Improve stiffness
- Improve fold-cracking resistance
- Improve print quality

Reduce Raw Material Costs

- Replace fibre with filler
- Reduce softwood pulp consumption
- Light weighting / dematerialization
- Reduce chemical consumption
- Reduce starch dependency

Gain Efficiency

- Reduce web breaks
- Improve retention
- Increase machine speed
- Reduce steam consumption
- Reduce refining energy

Improve Sustainability

- Use more recycled material
- MFC is recyclable, repulpable, biodegradable and compostable


Containerboard


White Top Liner


Coated recycled board


Folding box board


Graphic paper


Specialty papers


Coated paper


Tissue


3D Moulded Fibre

Grinder-Produced MFC: Paper segments

Typical uses of MFC in paper and board:

- Graphic paper – Filler increase and softwood reduction. Potential savings €25 – 35/ t
- Folding Box Board outer layers – chemical pulp reduction. Potential savings €25 – 35/ t
- Tissue – fibre reduction by light weighting. Potential savings €30 – 40/ t
- 3D moulded objects – fibre reduction by light weighting, improved formation, reduced porosity.
- New Product Developments:
  - Barriers, FiberLean on Top.

Graphic paper - reduce softwood, increase filler

Value creation with grinder produced MFC: Filler increase and softwood reduction

Background:

Offset paper: 70 g/m²
Base paper filler: 26%
Filler: PCC.
Market Hardwood & Softwood pulp.

Trial Outcomes:

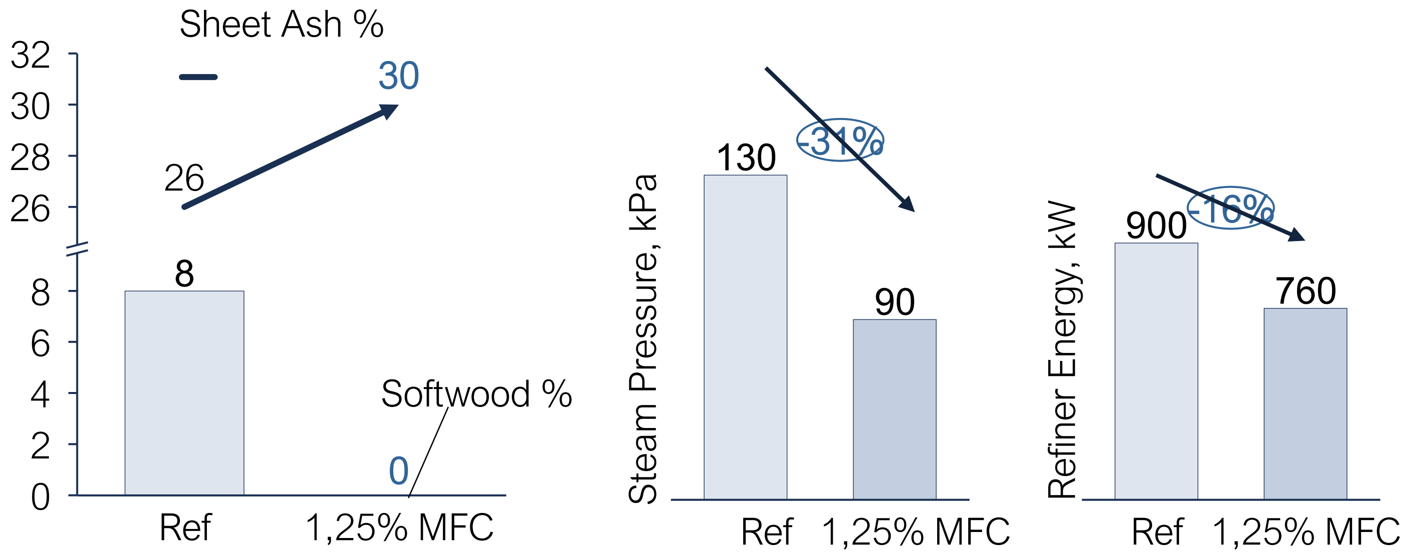
- 1.25% MFC addition.
- 4% filler increase (26% to 30%).
- Elimination of Softwood pulp (from 8 to 0%).

Benefits:

- ✓ Same specification at lower cost.
- ✓ Maintained runnability.
- ✓ 31% steam reduction.
- ✓ 16% refining energy reduction.
- ✓ Improved dimensional stability and flatness.

Value creation:

Cost savings 25 – 35 EUR/t (Net)



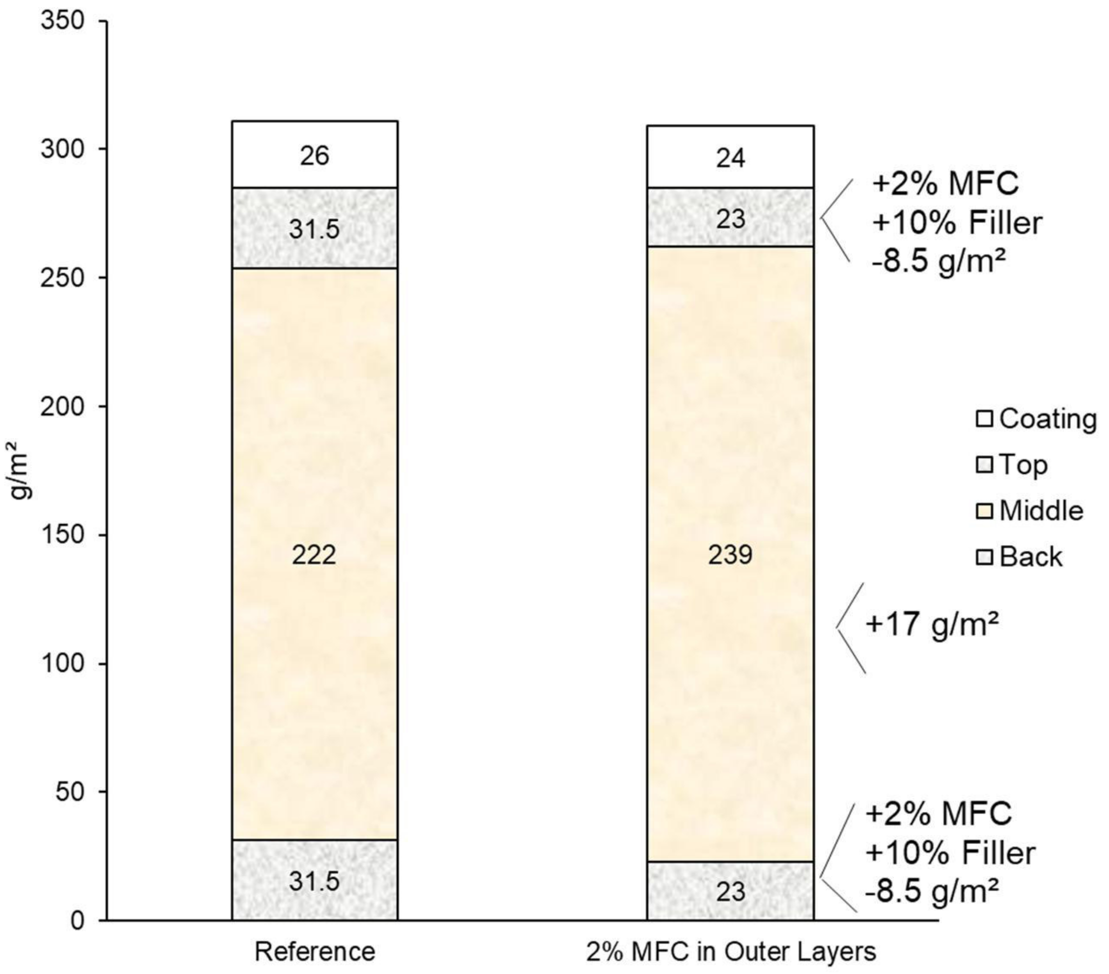
Replace fibre with filler

Reduce steam consumption

Reduce refining energy

Folding box-board – reducing pulp consumption

Value creation with grinder produced MFC: Filler increase & lightweighting of outer layers



Outcomes:

- 2% MFC, +10% filler (0-10%) in both outer layers
- -8.5 g/m² from each outer layer, replaced by middle layer

Benefits:

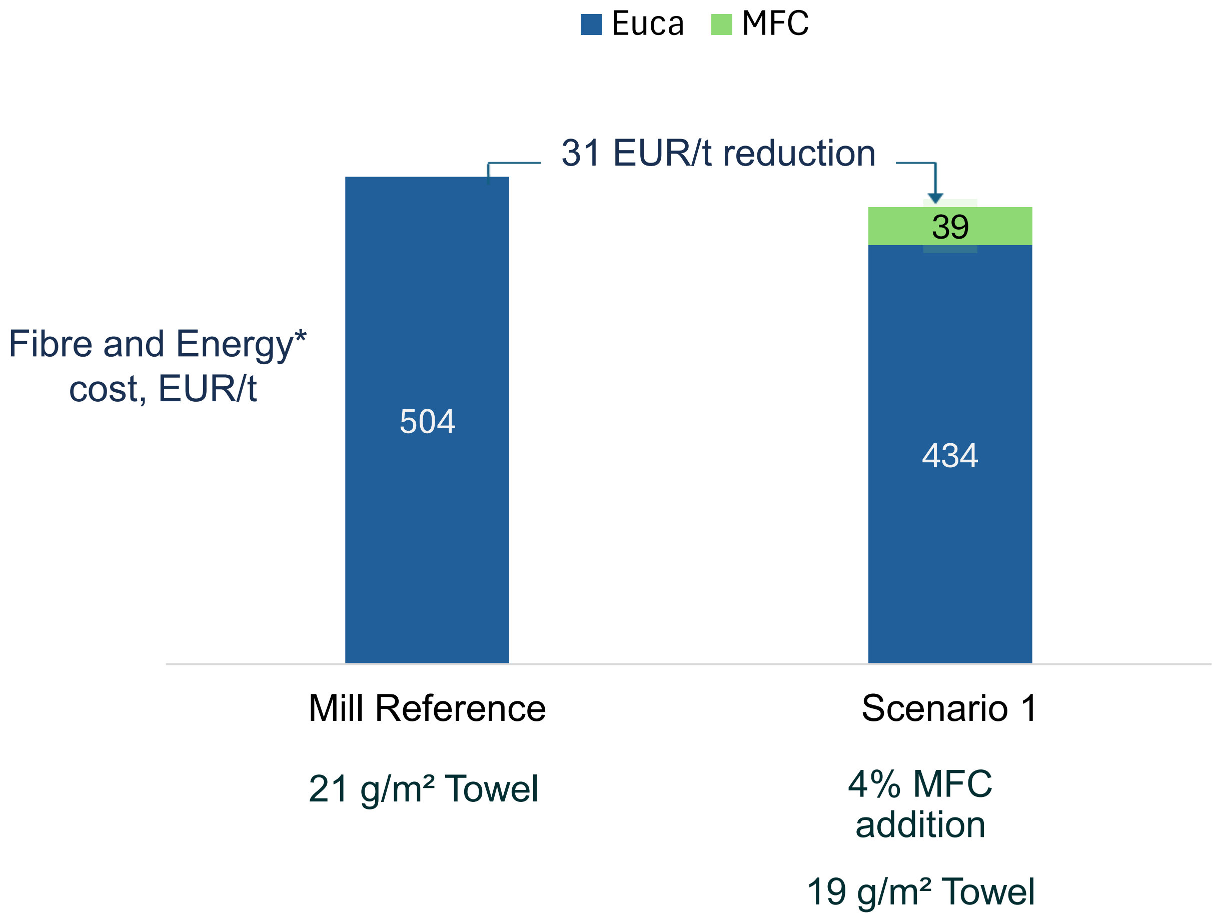
- ✓ **34% reduction of chemical pulp**
- ✓ Specification maintained at reduced costs
- ✓ Process parameters unchanged
- ✓ 50% reduction of ply bond starch required
- ✓ 1 pph pre-coat latex reduction
- ✓ 2 g/m² coat weight reduction

Value creation:

Cost savings 25-35 EUR/t (Net)

Tissue – fibre reduction by lightweighting

Value creation with grinder produced MFC: Lightweighting



*Energy cost includes MFC processing and fibre refining.

Outcomes:

- 4% MFC addition
- 2 g/m² basis weight reduction

Benefits:

✓ **10% reduction of pulp**

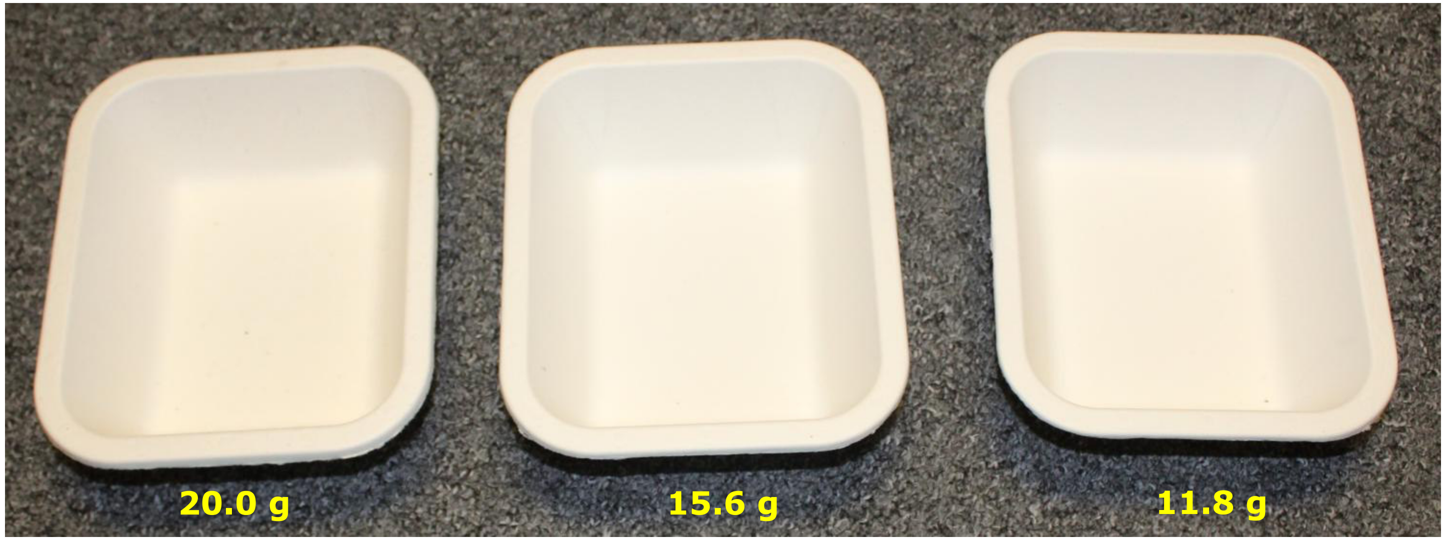
✓ Specification maintained at a reduced cost

Value creation:

Cost savings 30-40 EUR/t (Net)

FiberLean applications for 3D moulded fibre forms

***"Internal"** MFC application: Commercial scale-up in progress with selected partners*



(0% FiberLean® MFC) KIT = 0 out of 12

(10% FiberLean® MFC) KIT = 0 out of 12

(17% FiberLean® MFC) KIT = 4 out of 12

FiberLean® MFC) Content (%)	Tray Basis Weight (g/m^2)	Tensile stiffness index ($N\ m\ g^{-1}$)	Tensile strength index ($N\ m\ g^{-1}$)	Tensile stiffness ($N\ m^{-1}$)	Tensile strength ($N\ m^{-1}$)	Bendtsen Porosity ($ml\ min^{-1}$)
0	480	2.63	21.2	1270	10.2	2750
10	**380**	**3.45**	**37.2**	**1300**	**14**	**160**
17	**280**	**5.04**	**53**	**1430**	**15.1**	**15**
25	**175**	**5.37**	**56.4**	930	**9.8**	**4**

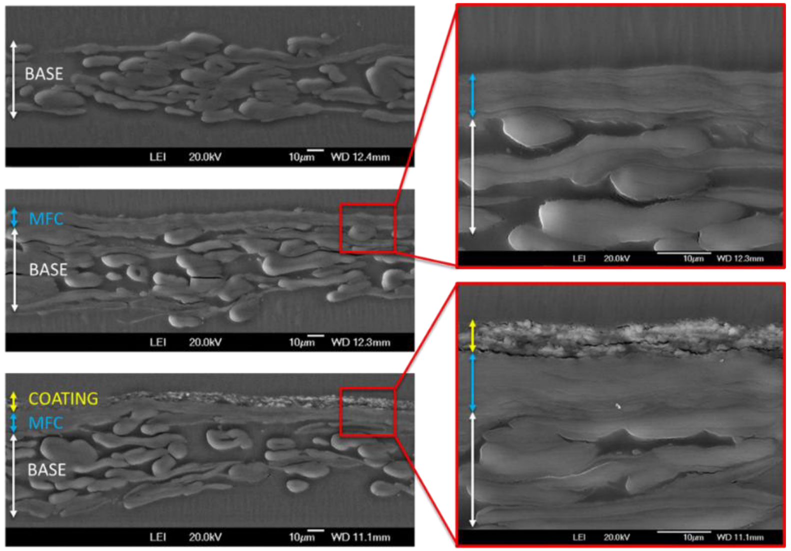
- Moulded objects such as trays prepared from bleached pulp can benefit from FiberLean® MFC:
- Up to 50% reduced object weight whilst maintaining strength, stiffness and mouldability.
- Greatly improved smoothness, and reduced permeability.
- Improved hold-out of functional coatings applied (e.g. Barriers) and effectiveness of sizing.
- OGR barrier properties (≥30% MFC results in KIT 12).
- Opportunity for replacement of PFAS.

FiberLean applications for 3D moulded fibre forms

***"Surface"** MFC application: Commercial scale-up in progress with selected partners*

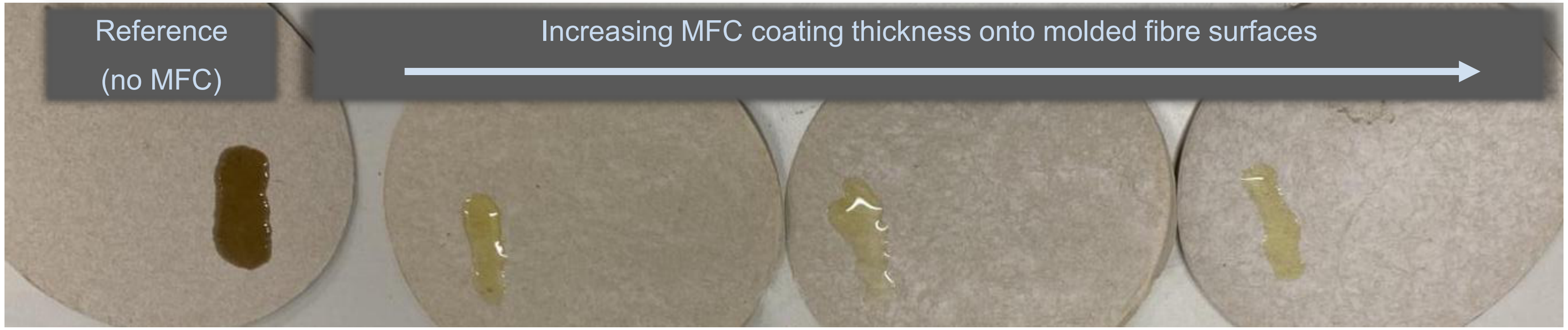
Sustainable Barriers & Precoated Surfaces

- ✓ Oil & Grease resistance.
- ✓ Oxygen & Aroma barrier.
- ✓ Mineral oil barrier.
- ✓ Very smooth & closed surface.
- ✓ Excellent substrate for coatings.
- ✓ High-strength & durable layer.
- ✓ High bio-based content, sustainable packaging.



Cross-section Imaging: Scanning Electron Microscopy (SEM)

- The MFC layer has a very closed structure, preventing penetration of oil and permeability of air.
- The surface serves as an excellent substrate (primer) for subsequent coatings.



- Initial trials applying MFC to the surface of molded articles.
- A simple test with olive oil drops demonstrates the MFC effect.

Use of MFC “on” molded objects: FiberLean on Top (FLOT)

New opportunity for application of MFC

FiberLean are the inventors & patent owners of this game-changing technology.

Image: 3-meter wide FiberLean on Top (FLoT) applicator operating on a paper machine running at 500 m/min

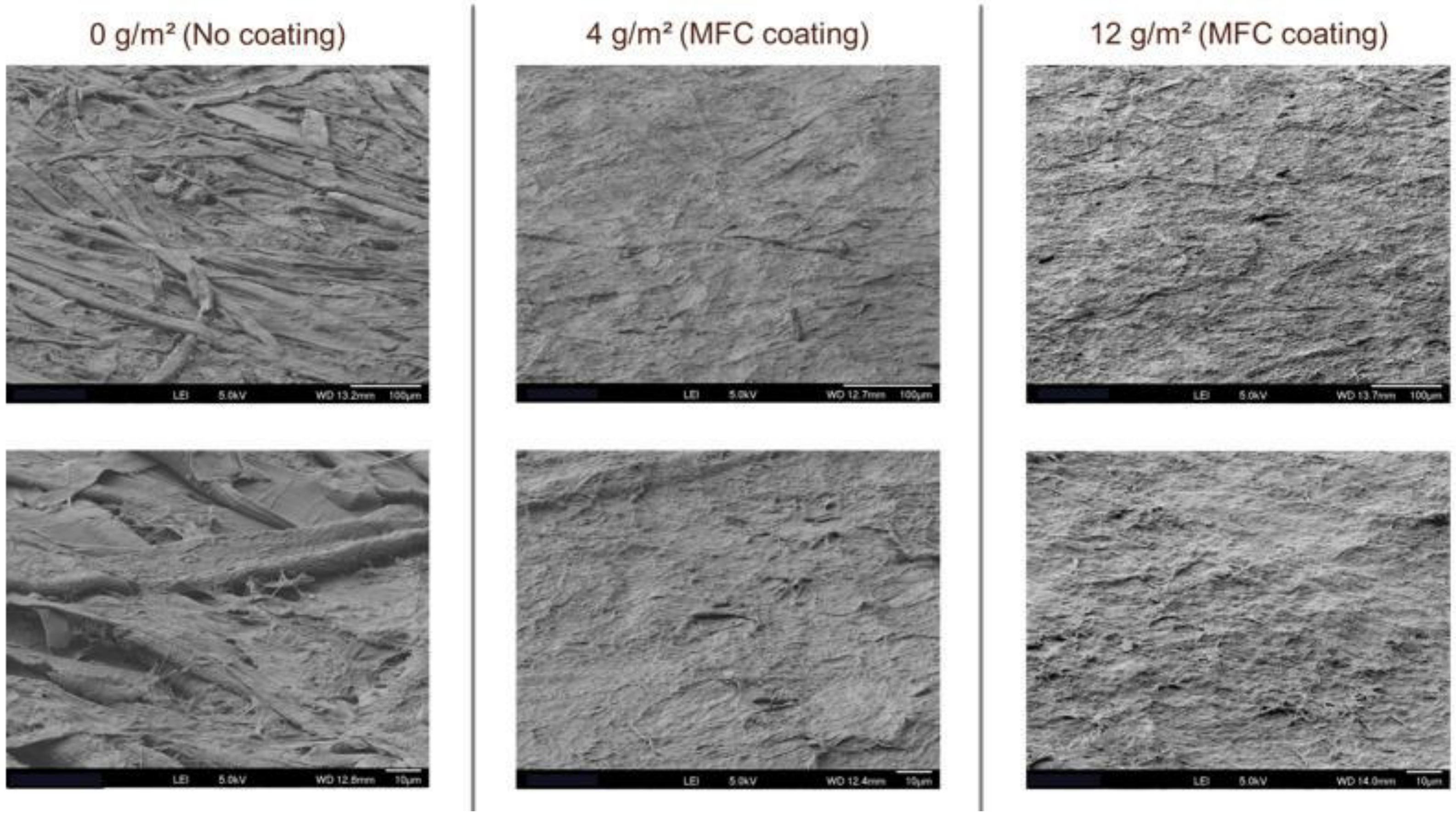
MFC is applied during the paper making process using FLOT applicator

Barrier

Providing barrier properties to help **reduce plastic** and other **harmful chemicals**

New product developments (i) Barriers

Scanning Electron Microscope (SEM) Images of MFC coated papers

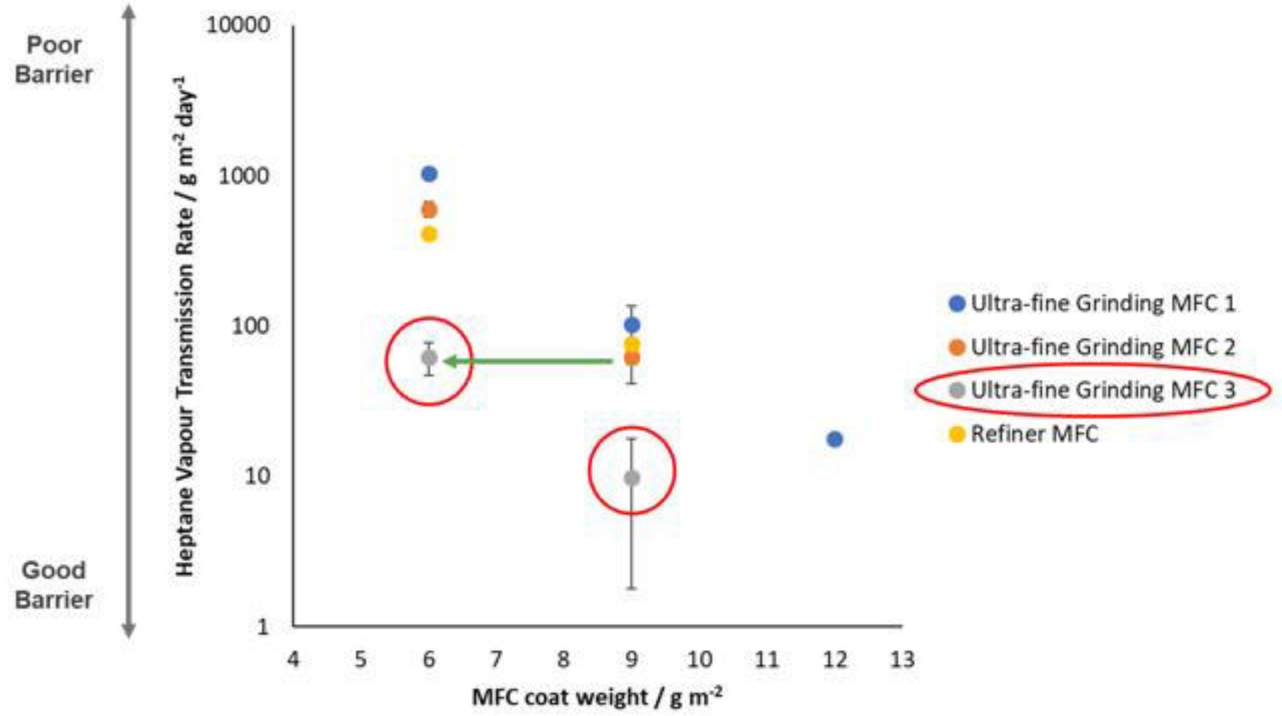


- The lowest coat weight, 4 g/m² provided substantial changes to the surface topography and structure.
- By 12 g/m², the MFC has formed a film and reached sufficient thickness to achieve high barrier properties.

The effect of pre-treatment and process conditions on the gas barrier properties of fibrillated cellulose films and coatings: A review, Hill et al, Carbohydrate polymers 337 (2024) 122085

New product developments (ii) Barriers

MFC Coat Weight vs. HVTR (23°C, 50% R.H.)
Various MFC samples coated onto paper

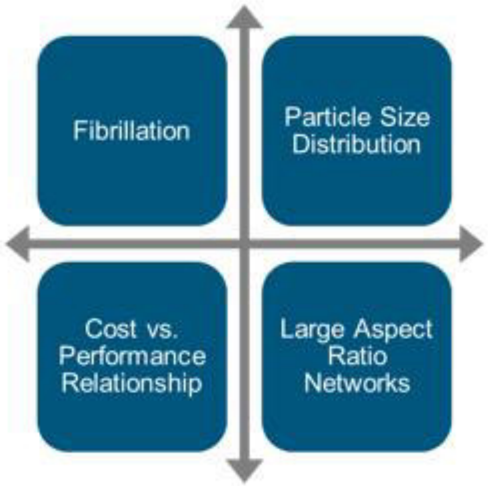


HVTR = Heptane Vapour Transmission Rate; is a barrier / permeation test method to evaluate the transmission rate of a volatile organic compound (n-Heptane), acting as a mineral oil simulant, through paper and plastic packaging materials.

○ = Product recommended for barrier MFC surface application.

✓ **Significantly lower coat weight required or higher performance.**

Tailored MFC Properties for Wet End Coating



- Barrier performance
- Strength / Durability
- Network bridging / film-forming
- Porosity control
- Surface hold-out
- Binding capability
- Viscosity & Drainage

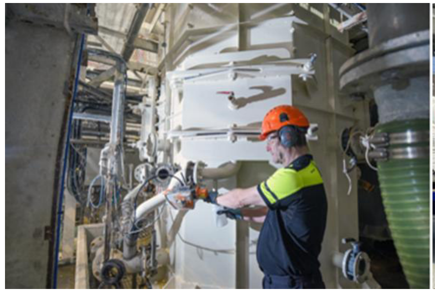
- Avoidance of applicator blockages
- Coating uniformity / formation
- Process throughput to match peak demand
- Dose / Coat weight required
- Cost effectiveness

Practicalities: Idea to implementation

Introduction meeting → Value creation refinement → Onsite MFC trials → Commercial offer → Contract negotiation → Grinder installation/ commissioning

Co-develop MFC value add

1. Identify the possible uses of MFC.
2. Develop business case.
3. Possible visit at Cornwall, UK.



Demonstration plant in Cornwall, UK

- Full-scale MFC production facility
- MFC produced in bags @ ~ 20% solids for trials

Paper machine trial to validate performance

1. Agree timing and cost.
2. FiberLean team and equipment travel to the site for offload preparation and installation.
3. FiberLean team operates the trial within the customer's production process.

MFC Re-suspension unit

End-to-end project delivery support by FiberLean:

1. Project engineering services to support design, procurement and construction.
2. Commissioning support and services.
3. Training for customer personnel.
4. Post-commissioning support available as needed.

FiberLean MFC Plant

Summary

- FiberLean grinders are an efficient and high throughput method for producing MFC.
- High quality MFC can be produced from a wide range of feed fibres with little to no equipment modification.
- The resultant MFC has:
  - High levels of surface micro and nano fibrillation whilst maintaining a coarse macrostructure.
  - Broad food contact clearance, is not a nano-material according to US EPA and EU definitions and no observed negative health effects.
  - Recyclable, biodegradable and compostible.
- Use of MFC from FiberLean grinders allows lighter products, reducing transport related emissions and supports recyclability and the circular economy by enabling plastic replacement in packaging.
- Use of MFC in paper and board leads to enhanced mechanical properties and reduced porosity sheets.
- Hence, offers opportunities for considerable cost savings in many specialty paper and board segments.
- Use of MFC both “in” and “on” moulded objects offers opportunities for lightweighting and property improvement.
- Implementation of FiberLean grinders is well established and follows a proven route via full-scale trials using MFC from FiberLean’s demonstration plant. FiberLean can support all project engineering stages.

Thank you

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FiberLean Technologies

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