Deutsches Biomasseforschungszentrum

DBFZ

Bioraffinerien

9th Expert Forum on Hydrothermal Processes

Biphasic Hydrothermal Fractionation of Alternative Feedstocks for Man-Made Cellulose Fibers and Platform Chemicals: Process and Scale-Up Perspectives

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9th-10th June 2026

Man-made cellulosic fibers (MMCFs)

Natural Cellulosic Fibers[1]

Regenerated Cellulosic Fibers[1]

- Global textile fibers:
  113 → 134 Mt/year by 2030 [2]
- Additional demand: +20 Mt/year
- Cotton limited growth: 26–28 Mt/year [2]
- Cotton cannot close the gap alone
- Wood-based dissolving pulp under pressure (climate stress, bioeconomy)[3]
- Need for alternative cellulose sources (residues)→ Fast-growing biomass → MMCF potential.

AltCell2 Project

OrganoCat
Fractionation

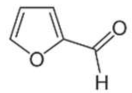
Plant screening → Biorefining

1) Cellulose
2) Hemicellulose
3) Lignin

Lab scale
(20 mL)

Technical Scale
(0.5–10 L)

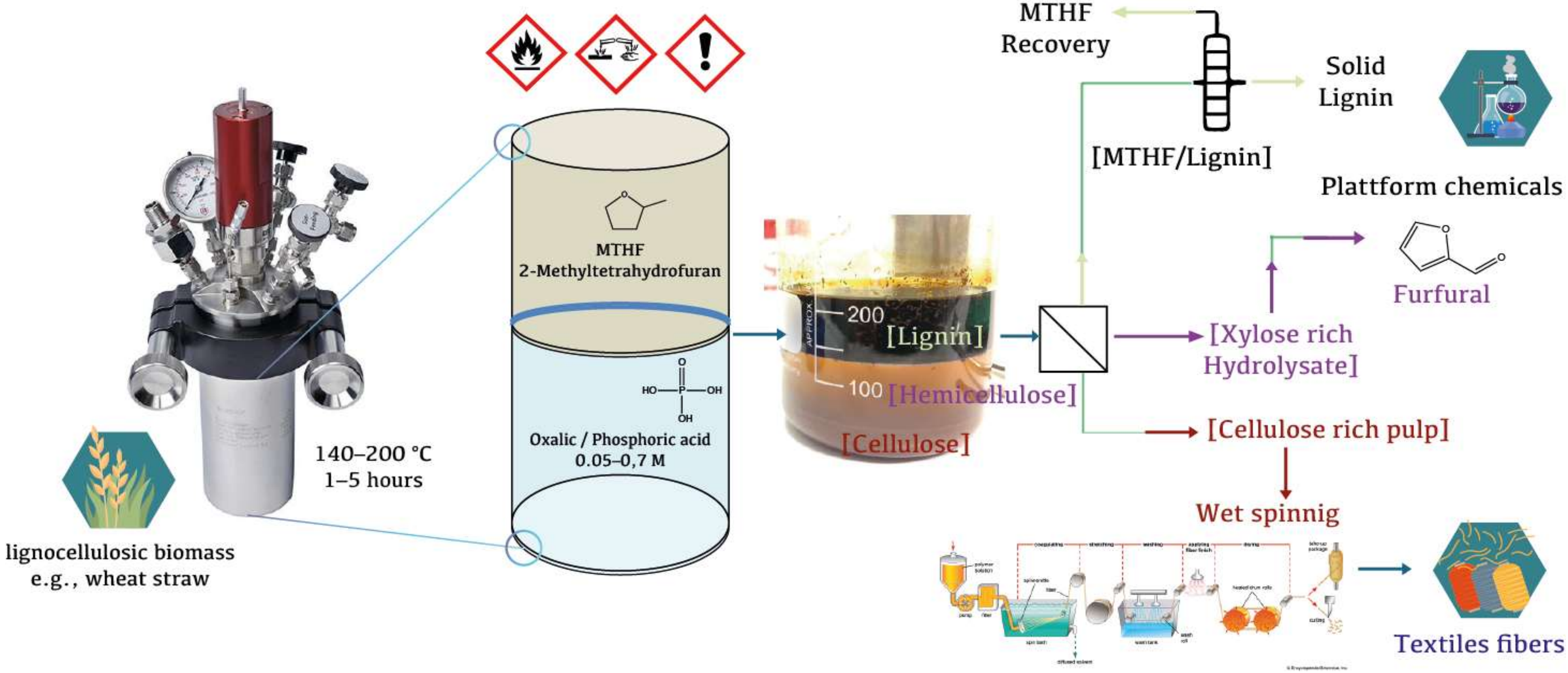
Fiber and textile production



Platform chemicals
[Furfural]

Product examples

Biphasic Hydrothermal Fractionation



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0.5 L Upscaling

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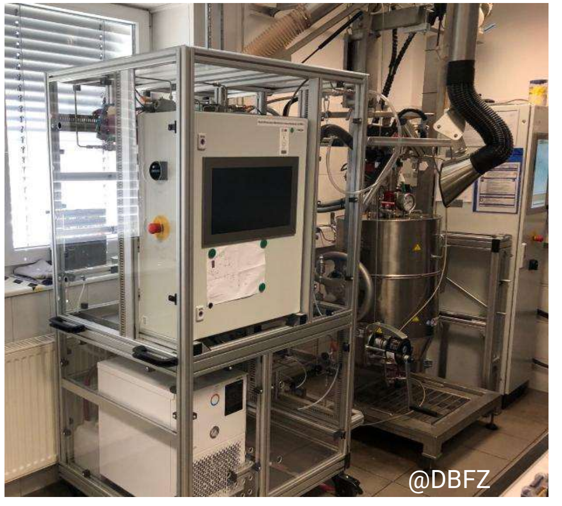
- System modified for biomass fractionation.
- Maximum filling volume estimation
- Phase separation behavior

- Solution:MTHF (1:1 ; 2:1)
- Acid solution (0.05–0.74 M)
- Temp (140, 160, 200, 220 °C)
- Particle size (0.5–1 mm)
- Reaction time (1–3 hr)

✓ 2-MTHF safety window
✓ Pressure profile generation
✓ Solvent expansion / density change
✓ Aspen Plus® modelling input

Modules for fractionation system (10 L)



✓ Reaction, Stirring & Collection module (RSCM)

1. Aspen-assisted volume estimation
Density change · thermal expansion
20–200 °C · 2-MTHF/H_3PO_4 phases.

✓ Hydrotheral membrane system (HTMV)

2. Fixed-volume reactor balance
Hot liquid volume · biomass moisture · dry biomass displacement · headspace.

3. Pressure validation

4. Effective gas/vapor volume
Pressure-calibrated headspace · VLLE behavior

5. Validated scale-up loading
Empirical correction · safe filling envelope.

Results

Table 1: Fractionation performance indicators

Process step	Mass balance equation
Pulp yield	$Y_{zs} = \frac{m_{zs}}{m_{ws}} \times 100\ \%$
Cellulose recovery	$R_{cell} = \frac{m_{cell,out}}{m_{cell,in}} \times 100\ \%$
Hemicellulose removal from pulp	$RM_{hemcell} = \left(1 - \frac{m_{hemcell,out}}{m_{hemcell,in}}\right) \times 100\ \%$
Lignin removal from pulp	$RM_{lign} = \left(1 - \frac{m_{lign,out}}{m_{lign,in}}\right) \times 100\ \%$
Lignin yield in organic phase	$Y_{lign} = \frac{m_{lign,recov}}{m_{lign,in}} \times 100\ \%$
Sugar yield relative to the dry matter content of wheat straw	$Y_s = \left(\frac{m_H + m_{PW}}{m_{WS}}\right) \times 100\ \%$
Xylose recovery	$\eta_{xyl} = \left(\frac{m_{xyl,recovered,total}}{m_{xyl,theoretical}}\right) \times 100\ \%$

For $x \in \{cell, lign, hemcell\}$ holds: $m_{x,in} = m_{ws} \cdot w_{x,ws}$ and $m_{x,out} = m_{zs} \cdot w_{x,zs}$

H: Hydrolysate; PW: Process water (washing stage)

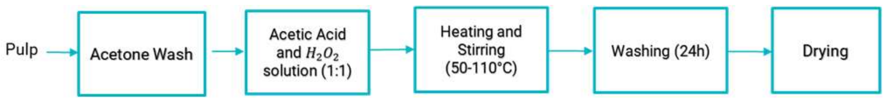
Table 2: High temperature MTHF fractionation–dry-matter basis (10 L system)

Experiment	p_{max} [bar]	Y_{zs} [%]	R_{cell} [%]	$RM_{hem.cell}$ [%]	RM_{lign} [%]	Y_{lign} [%]
1:1|140|0.74	16 ± 1	52 ± 0	84 ± 1	78 ± 1	62 ± 3	27 ± 1
2:1|140|0.74	16	52	76	86	66	17
1:1|200|0.05	27	48	91	84	81	56
2:1|200|0.05	29 ± 1	46 ± 1	69 ± 1	93 ± 2	80 ± 1	48 ± 1

- ✓ **Pulp yield** remains in a narrow range 48–52 %
- ✓ Interesting cellulose recovery: higher severity [Ratio 1:1 | 200 °C | 0.05 M] with up to 91 %.
- ✓ **Higher temperature improves fractionation:** hemicellulose removal remains high, while lignin removal increases strongly from **~62–66%** at 140 °C to **~80–81%** at 200 °C
- ✓ **Phase ratio matters:** increasing from **1:1 to 2:1** reduces cellulose recovery, so more solvent/aqueous phase is not automatically better

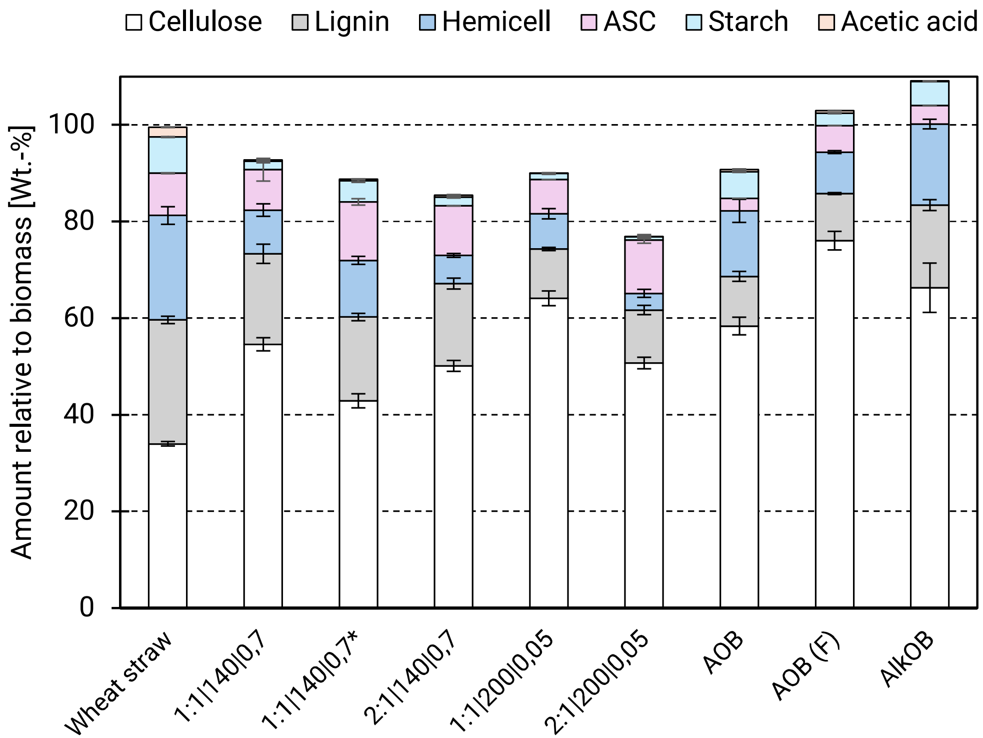
Pulp bleaching and biopolymers analysis

Pulp obtained after fractionation (left) and acidic bleached pulp (right) @ DBFZ



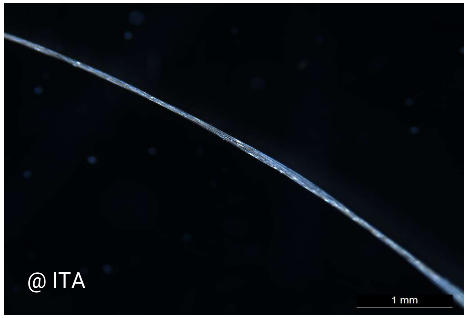
Acidic bleaching (© Andrés C. Acosta, 2026)

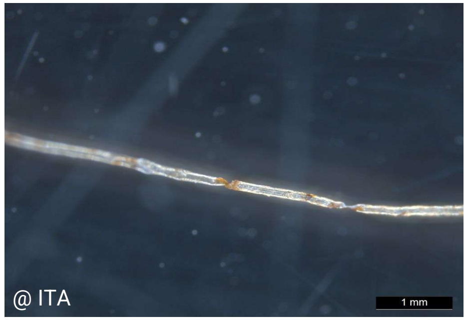
Alkaline bleaching (© ITA, 2026)

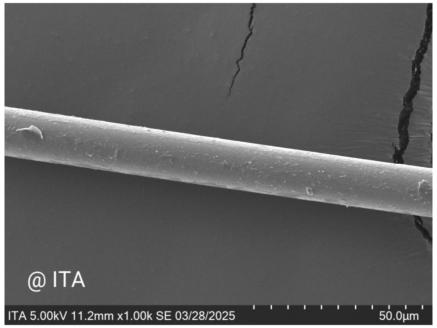


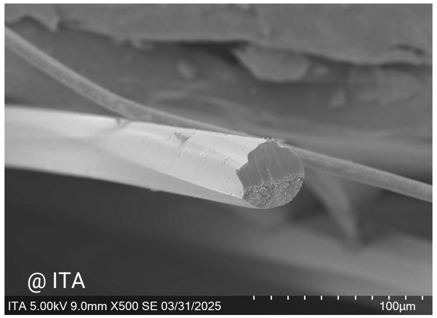
Biopolymer composition of pulp and bleached pulp (dry basis)
mean ± standard deviation based on three individual measurements (© Jülich Forschungzentrum; Andrés C. Acosta, 2026).

From Wheat Straw Pulp to Fibers (15 cm)









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Gel Permeation Chromatography (GPC)

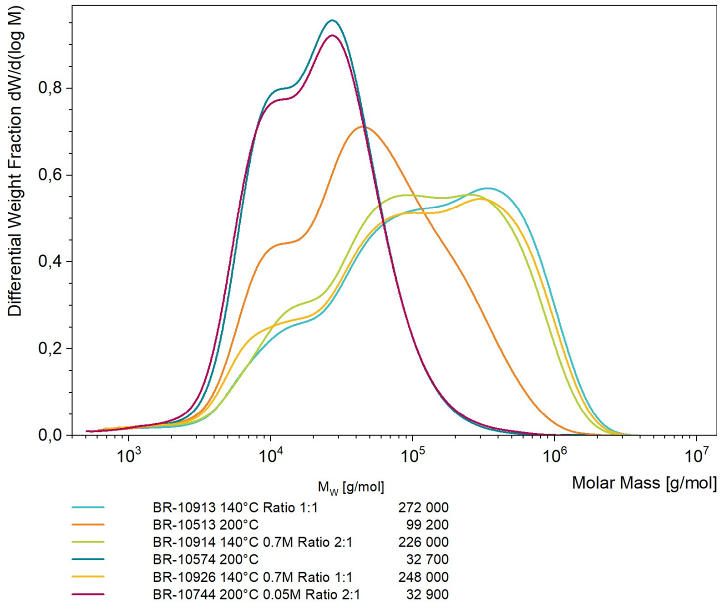


Table 3: GPC analysis of pulps

Experiment	M_n [kg/mol]	M_w [kg/mol]	D*	DP**
1:1|140|0.74	32	272	8,6	722
2:1|140|0.74	16	52	7,7	628
1:1|200|0.05	27	48	5,2	276
2:1|200|0.05	29	46	2,5	91

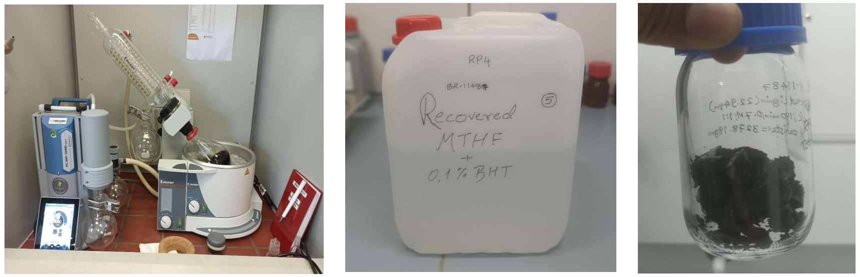
* **Dispersity** is defined as the ratio of **Mw to Mn**.
** The **degree of polymerization** was calculated based on the average molar mass of the **anhydroglucose unit** of cellulose

✓ **Target for processing: DP > 200**

- **High D: broad chain-length distribution**
- **Low D: more homogeneous cellulose pulp**

Xylose rich hydrolysates

View into the modified HTMV (left) and phase separation of the organic phase (right) (© Andrés C. Acosta, 2026).



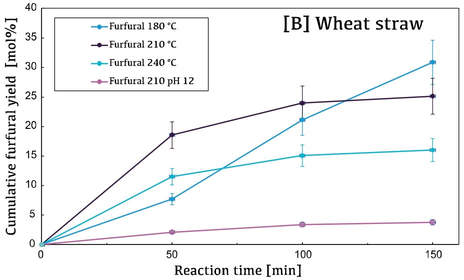
MTHF Recovery (© Andrés C. Acosta & A. Sunil 2026)

Table 3: High temperature MTHF fractionation–dry-matter basis (10 L system)

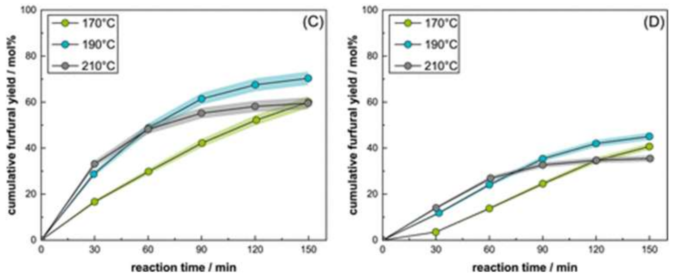
Experiment	Glucose	Xylose	Arabinose	Mannose	HMF	Furfural
	(mg/L)					
1:1|140|0.74	634 ± 66	4315 ± 120	524 ± 37	n.d	n.d	254 ± 75
2:1|140|0.74	658	4290	422	n.d	n.d	459
1:1|200|0.05		n.d	n.d	3030	222	492
2:1|200|0.05	227 ± 42	n.d	69 ± 1	3875 ± 191	80 ± 1	871± 21

Sugar monomers measured with HPLC-RID and Furanic aldehydes with HPLC-DAD
Lignin is recovered using the rotary evaporator
Acosta, A. C. (2025). [Dissemination video]. Fast Forward Science 2025[4].

Hydrothermal reactive distillation (HRD)

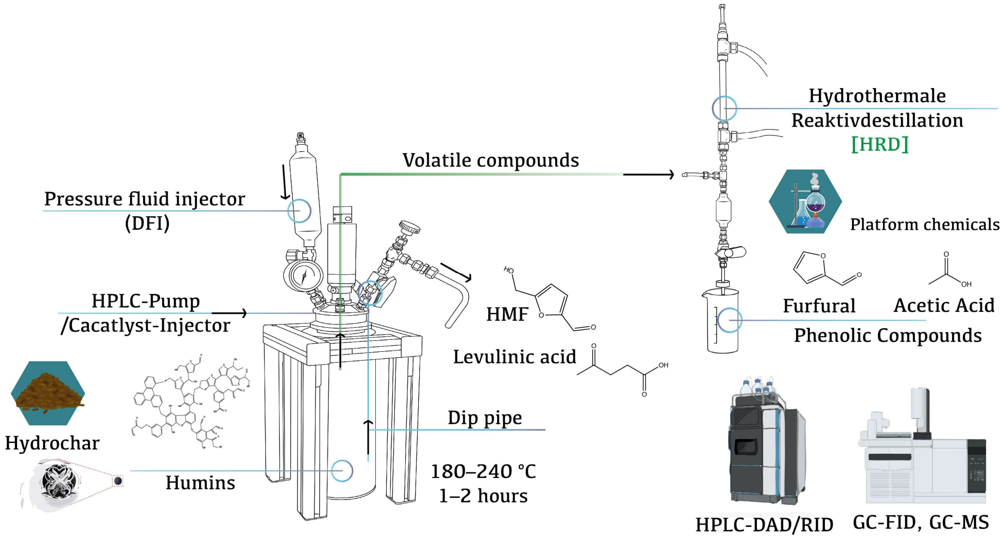


Cumulative furfural yield using Wheat Straw (© Köchermann & Acosta; 2026)



Cumulative furfural yield seplt husk hydrolysate (left) and Organosolv hemicellulose (right) (© Köchermann & Klemm; 2023)[5]

✓ Hydrothermal reactive distillation for furfural synthesis.



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(© Köchermann & Klemm; 2023)[5]
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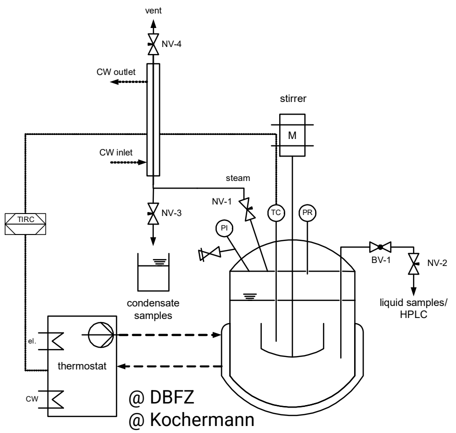
Hydrothermal reactive distillation (HRD)



Reflux condenser design and installation in fume hood.

Upscaling HRD system in Hydrotheral membrane system (HTMV) for integration to 10 L reactor

(© Köchermann & Klemm; 2023)[5]
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Thank you !

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References

[1] https://mikem.com/news/what-is-cellulose-fiber/
[2] https://doi.org/10.1016/j.jil.2025.100178.
[3] https://datalab.dbfz.de/resdb?lang=en
[4] Acosta, A. C. (2025). [Dissemination video]. Fast Forward Science 2025
[5] https://doi.org/10.1021/acs.iecr.3c00259

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