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Electronic Supporting Information

Sustainable low-cost carbon fibres produced by integrating wood fractionation with lignin fibre spinning

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1. Detailed experimental methods

1.1 Preparation of reconcentrated black liquors (BL30 and BL40)

Air-dried milled eucalyptus wood (9 or 12 g oven-dried weight) was added into a 100 mL pressure tube (Ace Glass, Vineland, NJ, USA, front sealing), followed by *ca*. 30 g [DMBA][HSO_4] (water content 17 wt%) and water to obtain a 30% or 40% biomass loading and 20% water content in the liquid. The lignin extraction was carried out in triplicate. The wood and ionic liquid solution were mixed with a vortex shaker until all wood particles were in contact with the IL. The pressure tubes were placed in a preheated fan-assisted oven for 1 h at 150°C. The suspension was allowed to cool on the bench in the pressure tubes and transferred into a 500 mL glass bottle, followed by mixing with 180 g absolute ethanol to facilitate separation of the black liquor from the cellulose pulp, shaken well and rested for 1 h at room temperature. The suspension was separated into the solid cellulose pulp and a liquid that contained ionic liquid, ethanol and solutes including the extracted lignin (liquor) using vacuum filtration employing cellulose filter paper (Whatman 542, hardened, ashless). The pulp was washed with absolute ethanol three more times, followed by a Soxhlet extraction with ethanol for 24 h, air-drying and storage. The liquid fractions were collected, and most of the ethanol evaporated from the combined fractions using a rotary evaporator to obtain Black liquor 30 (BL30) and Black Liquor 40 (BL40).

1.2 Calculating the lignin loading

The lignin content or lignin fraction in the black liquor ($\mathrm{L_{lignin}}$) was defined as the weight ratio (in wt/wt %) of dissolved lignin in the black liquor relative to all components in the black liquor according to Equation 1.

$$L_{lignin} = \frac{m_{lignin}}{m_{liquor}} \cdot 100\%$$

Equation 1

The weight of dissolved lignin was calculated using the weight of lignin in the eucalyptus wood used for each experiment and the weight of lignin remaining in the cellulose pulp (both obtained by composition analysis and measuring the pulp yield (shown in

Table S2) according to Equation 2:

$$\mathrm{m_{lignin}} = \mathrm{m_{lignin(wood)}} - \mathrm{m_{lignin(pulp)}}$$

Equation 2

The lignin content in the wood and cellulose pulp was assumed to be the sum of the acid-insoluble (AIL) and acid-soluble lignin (ASL) in the eucalyptus wood and the pulp, respectively. Multiplying the lignin content with the oven-dried weight of the wood used in the experiment and pulp generated during fractionation yielded the weight of lignin added into the ionosolv liquid with the wood (Equation 3) and the weight of non-extracted lignin in the pulp (Equation 4).

$$m_{lignin(wood)} = \frac{AIL + ASL}{100\%} \cdot m_{wood}$$

Equation 3

$$m_{lignin(pulp)} = \frac{AIL + ASL}{100\%} \cdot m_{pulp}$$

Equation 4

The integral of the methyl group in ethanol (A_{EtOH}) at δ_H (400 MHz, DMSO-d_6)/ppm: 1.05, t and integral of the methyl group on the butyl group of the *N,N*-dimethylbutylammonium cation (A_{IL}) at δ_H (400 MHz, DMSO-d_6)/ppm: 0.90, t were used for calculating the molar ratio of IL and EtOH, which was converted to a weight ratio by multiplication with the molar weight of the IL and alcohol. A 1:1 ratio of acid to base (or cation to anion) was assumed for [DMBA][HSO_4] in the black liquor.

$$R_{IL:EtOH} = \frac{A_{IL} \cdot 199.3\, g/mol}{A_{IL} \cdot 199.3\, g/mol + A_{EtOH} \cdot 46.07\, g/mol} : \frac{A_{\,EtOH} \cdot 46.07\, g/mol}{A_{\,IL} \cdot 199.3\, g/mol + A_{\,EtOH} \cdot 46.07\, g/mol}$$

Equation 5

1.3 Calculations to obtain the required dope compositions

The ratio of PVA to water in the stock solution was determined by the target lignin:PVA weight ratio in the fibre, the measured proportions of lignin and water in the black liquor, and the target water proportion of the dope solvent. The result is shown in Equation 6 and Equation 7, followed by the definition of terminology and the derivation.

$$R_{PVA:H_2O,stock} = \frac{F_{lig,BL}\left(1 - F_{H_2O,dope}\right)}{F_{H_2O,dope}\left(F_{lig,BL} + R_{lig:PVA}\right) - F_{H_2O,BL} R_{lig:PVA}}$$

Equation 6

$$m_{stock} = m_{BL}\left(1 + \frac{1}{R_{PVA:H_20,stock}}\right)\frac{F_{lig,BL}}{R_{lig:PVA}}$$

Equation 7

Where we use the following terminology:

- $m_{X[,Z]}$: the mass of component X in solution Z. The square brackets around Z are to indicate that it is only specified where necessary (*i.e.* when X is water, since it is the only component present in more than one source solution).
- m_Z: the mass of solution Z.
- $R_{X:Y[,Z]}$: the weight ratio of component X to component Y in solution Z. The solution, Z, is only specified where necessary.
- $F_{X,Z}$: the fractional weight of component X in solution Z.
- The components are: PVA, H_2O and lig (lignin).
- The solutions are: $stock$ (aqueous PVA stock), BL (black liquor) and $dope$ (target solution).

For clarity we state:

$$R_{X:Y[,Z]} = \frac{m_{X[,Z]}}{m_{Y[,Z]}}$$

Equation 8

$$F_{X,Z} = \frac{m_{X[,Z]}}{m_Z}$$

Equation 9

So, the measured and target quantities used in Equation 6 and Equation 7 are:

$$F_{lig,BL} = \frac{m_{lig}}{m_{BL}}$$

Equation 10

$$F_{H_2O,BL} = \frac{m_{H_2O,BL}}{m_{BL}}$$

Equation 11

$$R_{lig:PVA} = \frac{m_{lig}}{m_{PVA}}$$

Equation 12

$$F_{H_2O,dope} = \frac{m_{H_2O,dope}}{m_{dope}}$$

Equation 13

We also note that:

$$m_{H_2O,dope} = m_{H_2O,stock} + m_{H_2O,BL}$$

Equation 14

$$m_{dope} = m_{H_2O,stock} + m_{PVA} + m_{BL}$$

Equation 15

To derive Equation 6, we substitute Equation 14 and Equation 15 into Equation 13 and rearrange:

$$m_{H_2O,stock} = F_{H_2O,dope}\left(m_{H_2O,stock} + m_{PVA} + m_{BL}\right) - m_{H_2O,BL}$$

Equation 16

Using Equation 11 to eliminate $m_{H_2O,BL}$ from Equation 16 and rearranging yields:

$$m_{H_2O,stock}\left(1 - F_{H_2O,dope}\right) = F_{H_2O,dope}(m_{PVA} + m_{BL}) - F_{H_2O,BL}m_{BL}$$

Equation 17

We combine Equation 10 and Equation 12 to obtain:

$$\frac{m_{BL}}{m_{PVA}} = \frac{R_{lig:PVA}}{F_{lig,BL}}$$

Equation 18

And from Equation 8 we note that:

$$\frac{m_{H_2O,stock}}{m_{PVA}} = R_{H_2O:PVA,stock}$$

Equation 19

By dividing both sides of Equation 17 by m_{PVA}, substituting in Equation 18 and Equation 19, and rearranging, we obtain:

$$R_{H_2O:PVA,stock} = \frac{F_{H_2O,dope}\left(F_{lig,BL} + R_{lig:PVA}\right) - F_{H_2O,BL}R_{lig:PVA}}{F_{lig,BL}\left(1 - F_{H_2O,dope}\right)}$$

Equation 20

Equation 6 is then obtained by inverting Equation 20, noting that $R_{X:Y,Z} = 1/R_{Y:X,Z}$.

To derive Equation 7, we start with:

$$m_{stock} = m_{PVA} + m_{H_2O,stock}$$

Equation 21

Using Equation 19 to eliminate $m_{H_2O,stock}$ from Equation 21 yields:

$$m_{stock} = m_{PVA}\left(1 + R_{H_2O:PVA,stock}\right)$$

Equation 22

Using Equation 18 to eliminate m_{PVA} from Equation 22 and inverting the ratio yields Equation 7.

The target lignin:PVA ratios, $R_{lig:PVA}$, in the fibres in this study were 3:1 or 75:25 and 4.71:1 or 82.5:17.5. The target water content in the dope (including lignin), $F_{H_2O,dope}$, was set to 0.20.

2. Compositional analysis data

Table S1: Compositional analysis data for as received eucalyptus wood and cellulose pulp obtained after producing the two black liquors

	Eucalyptus wood	**Pulp (30% biomass loading)**	**Pulp (40% biomass loading)**
Glucan (%)	46.9 ± 0.3	80.9 ± 7.7	81.7 ± 0.7
Xylan (%)	8.9 ± 0.1	2.6 ± 1.2	2.1 ± 0.0
Galactan (%)	-	-	-
Arabinan (%)	-	-	-
Mannan (%)	-	-	-
ASL (%)	7.4 ± 0.0	4.7 ± 0.1	4.7 ± 0.1
AIL (%)	29.5 ± 0.1	12.1 ± 1.0	15.3 ± 0.3
Ash (%)	-	-	-
Extractives (%)	1.6 ± 0.2	-	-
Mass closure (%)	94.3	104.8	103.7

Table S2: Key data for the lignin extraction after eucalyptus wood fractionation with [DMBA][HSO$_4$] with 20% water at 150°C for 1 h.

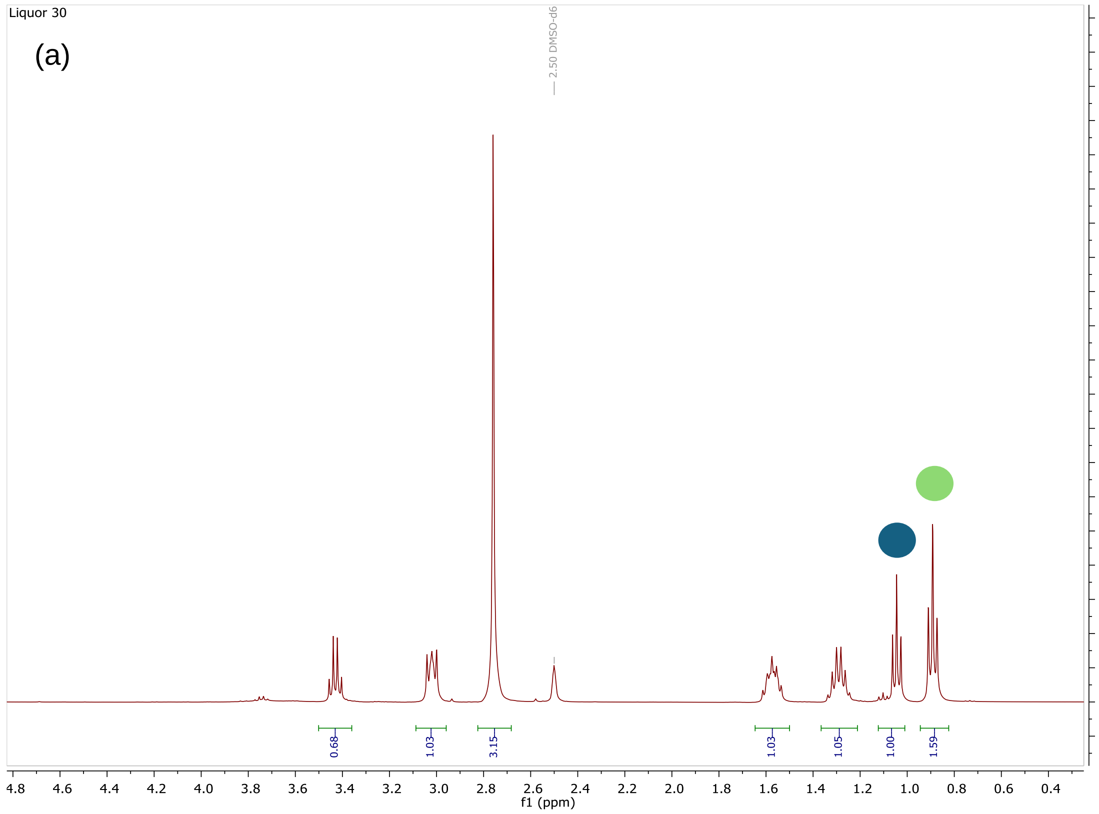
	Cellulose pulp yield (%)	**Lignin content in biomass/pulp (%)**	**Lignin extracted (%)**
Eucalyptus wood		36.8 ± 0.1	
Eucalyptus pulp 30% loading	45.6 ± 2.3	16.8 ± 0.9	80.0 ± 2.1
Eucalyptus pulp 40% loading	51.0 ± 0.5	19.9 ± 0.2	72.5 ± 0.5

Table S3: Composition of reconcentrated black liquors obtained after extracting lignin from eucalyptus wood with [DMBA][HSO$_4$] water mixtures.

Sample	**Biomass to solvent ratio in ionosolv fractionation**	**Lignin fraction in black liquor (wt%)**	**Water fraction in black liquor (wt%)**	**IL:EtOH:water fraction in dope solvent (wt%)***
Black liquor 30	3:10	8.8 ± 0.2	0.8 ± 0.1	85:14:1
Black liquor 40	4:10	10.0 ± 0.1	0.6 ± 0.1	88:11:1

*Standard error of the mean < 2%

3. ^{1}H-NMR spectra of black liquors



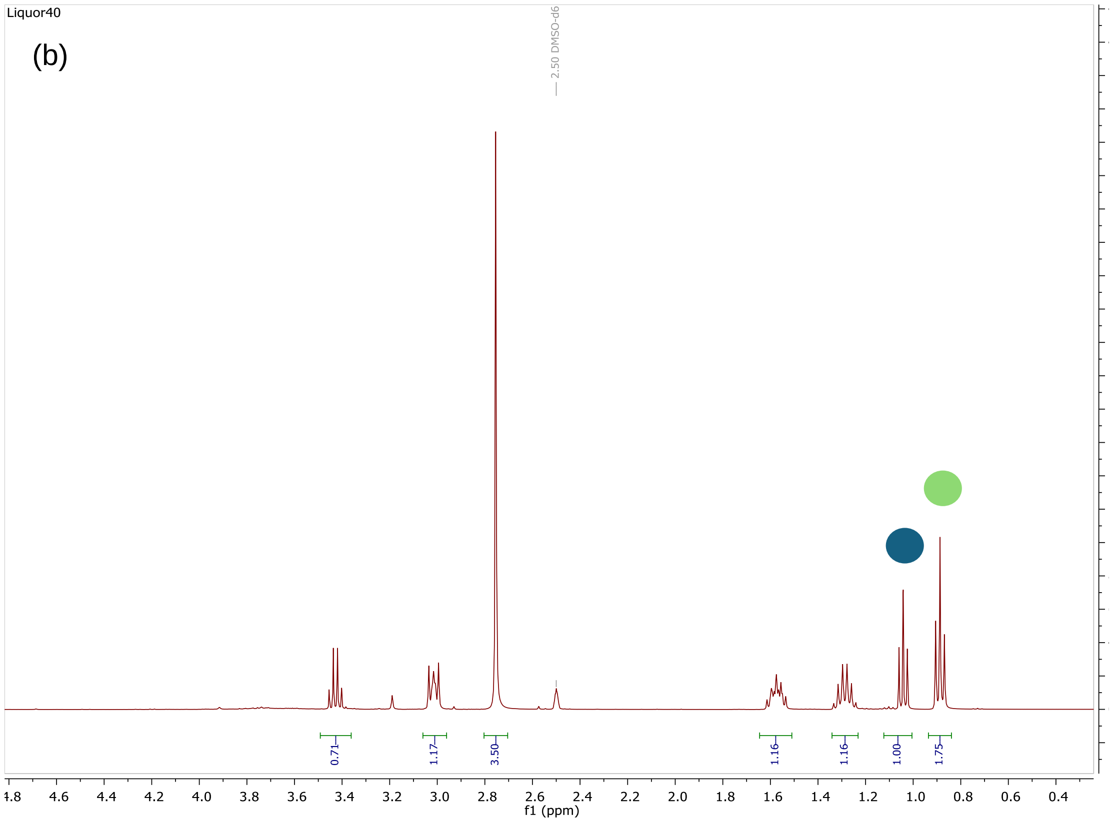


Figure S1. ^{1}H NMR spectra of (a) Black Liquor 30 (b) Black Liquor 40. The Peak labelled with a green dot is a methyl group in [DMBA][HSO_4]. The peak labelled with a blue dot is the methyl group in EtOH. These peaks were used for determining the IL and EtOH molar ratio in the liquors.

3. Optical micrographs of black liquors, PVA stock solutions and dopes

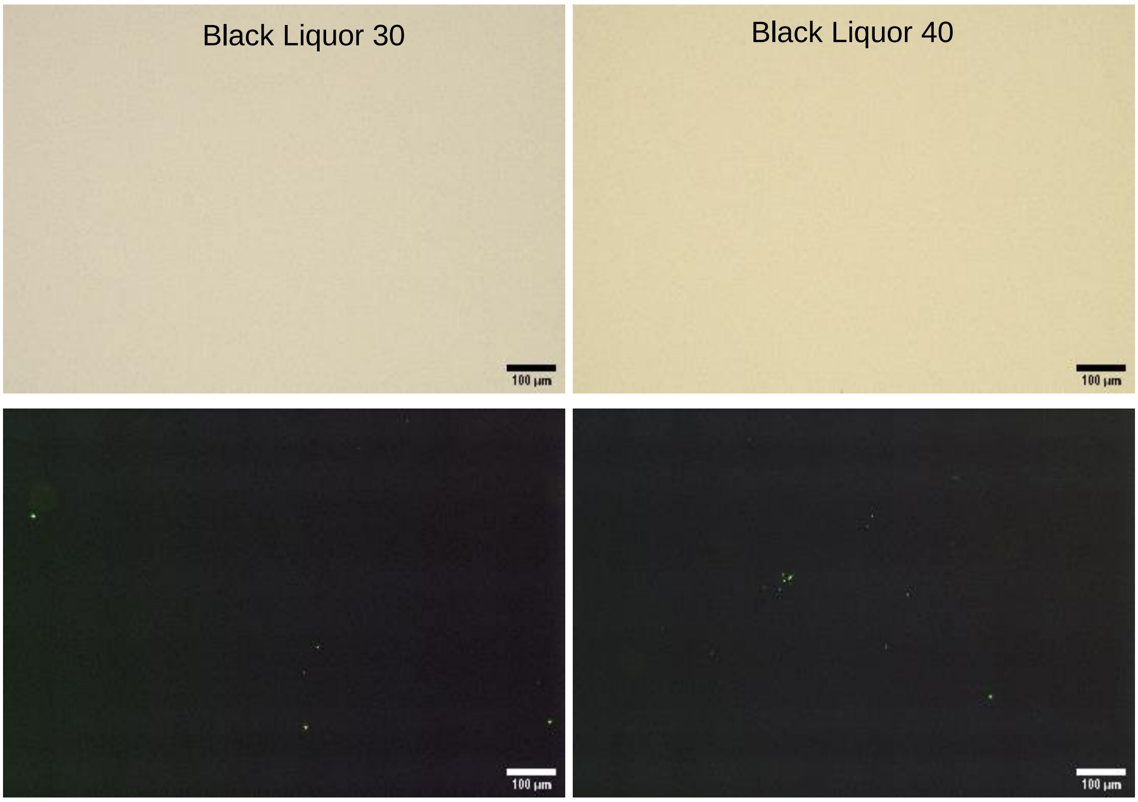


Figure S2. Optical micrographs of ionosolv black liquors after ethanol evaporation. Images were taken using widefield illumination (top) and with cross-polarisers (bottom). The size of the scale bar is 100 µm.

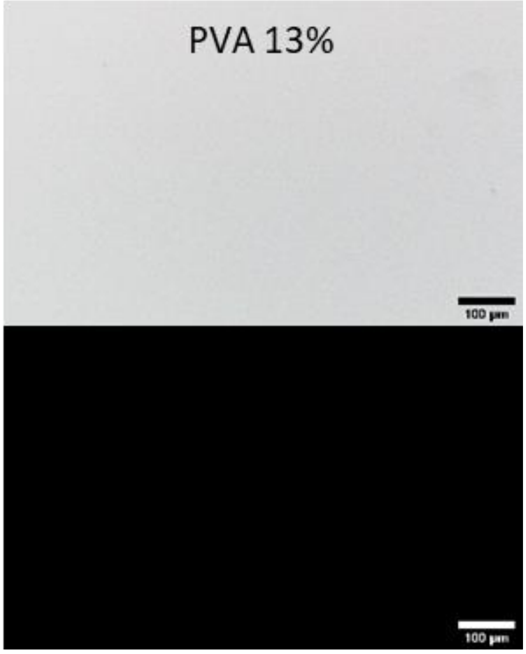


Figure S3. PVA stock solution imaged with an optical microscope. The bottom image was obtained with crossed polarisers.

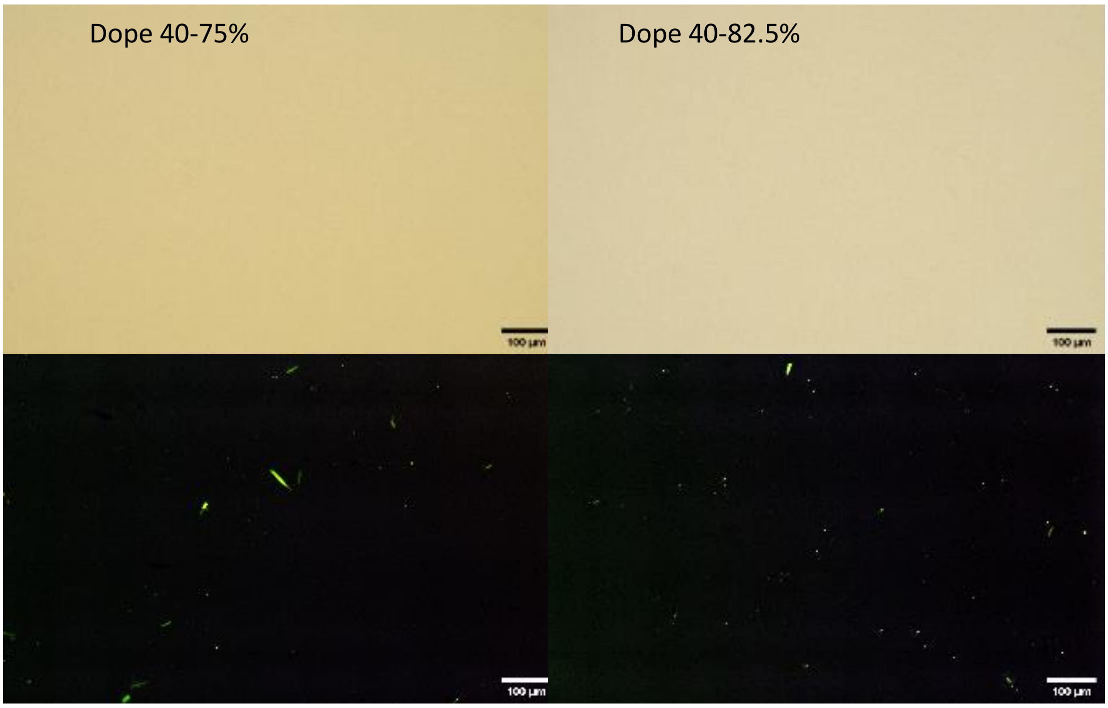


Figure S4: Samples of 75% Lignin Dope 40 (1 h) and 82.5% Lignin Dope 40 (1 h) imaged with an optical microscope. The bottom images were obtained with crossed polarisers.

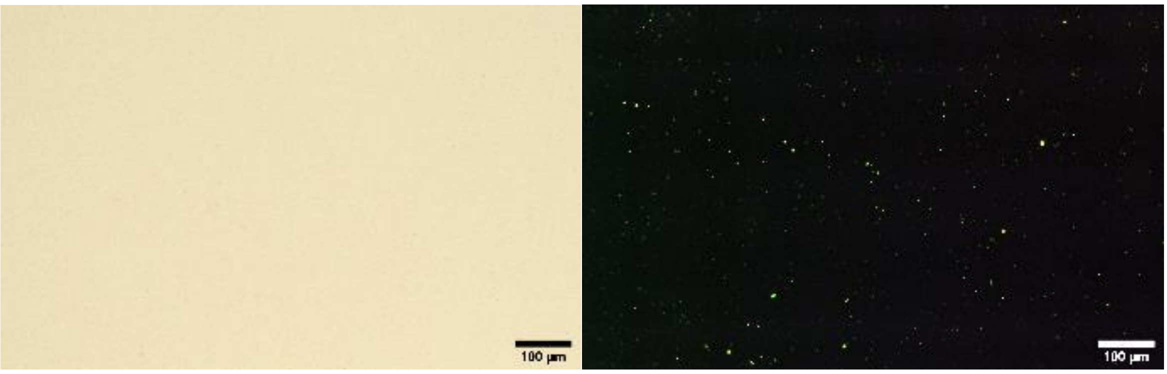


Figure S5. Optical micrographs of 75% Lignin Dope 30 (1 h). The right-hand side image was obtained with crossed polarisers.

4. Effect of dope rheology on lignin fibre spinning

Monitoring the behaviour of solutions in flow is useful for discussing phenomena observed for fibre formation, hence shear viscosities were measured for the black liquors and spinning PVA containing dopes using a dynamic rotational rheometer. Data are shown in Figure S6 (a) and (b).

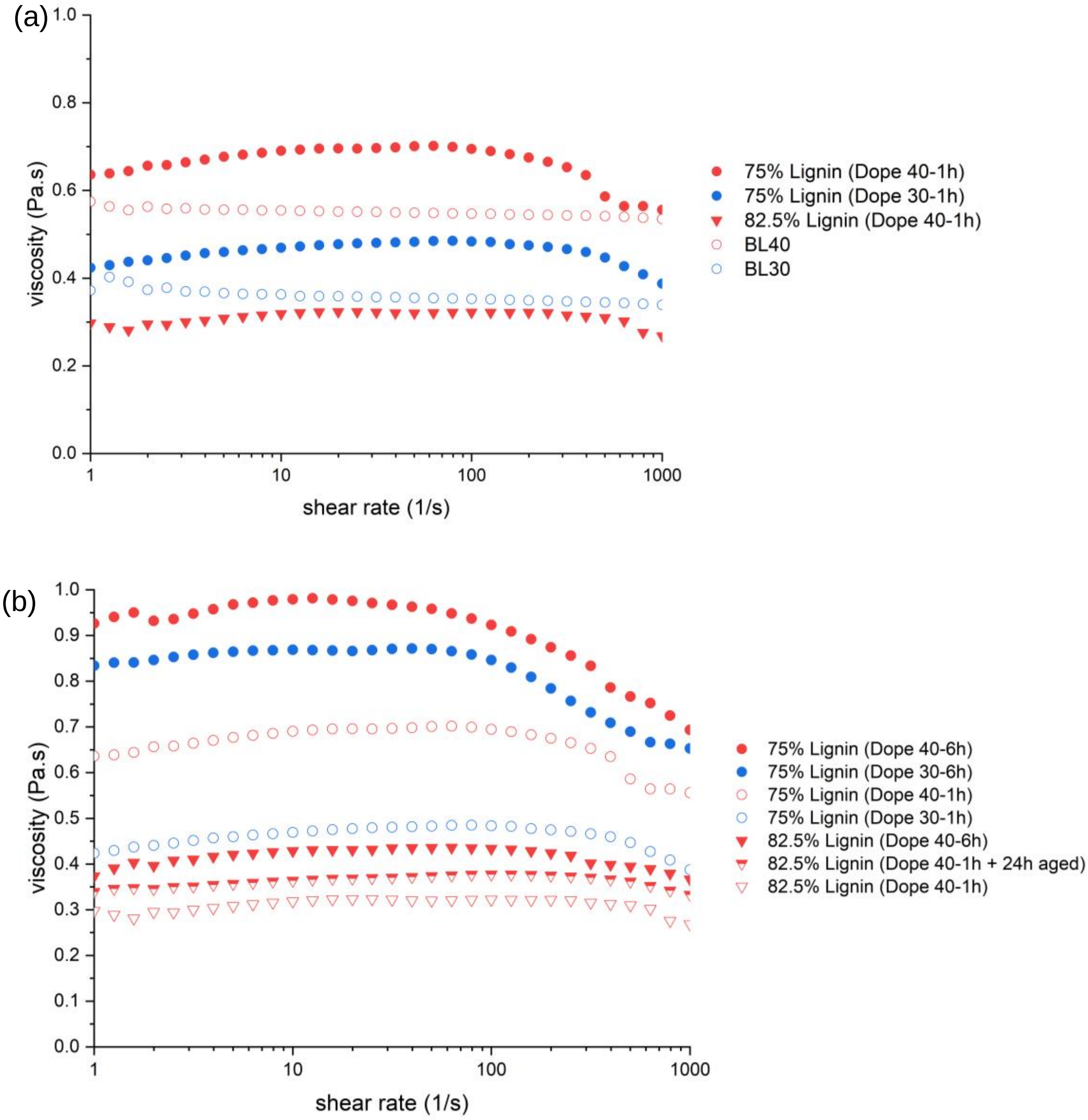


Figure S6: (a) Shear viscosity of ionosolv black liquors obtained with 30% and 40% eucalyptus wood loading and the corresponding spinning dopes with different lignin to PVA ratio (75% or 82.5% lignin content in lignin PVA fibre) prepared for 1 h; (b) Shear viscosity of dopes containing varying lignin/PVA ratios (lignin content = 75% or 82.5%), prepared from BL 30 and BL40 and mixed with PVA for 1 h or 6 h. The aged dope was left on the bench for 24 h before analysis.

The viscosity of the black liquors was relatively low (0.4-0.6 Pa·s) and did not change with shear rate or time (Figure S6a), which was expected for an ionic liquid water mixture containing polydisperse mostly low molar weight solutes, such as hydrolysed lignin and hemicellulose fragments. The black liquor produced with 40% biomass loading had a higher viscosity (*ca.* 0.6 Pa·s) than the black liquor obtained with 30% biomass loading (0.4 Pa·s), which is ascribed to the higher solute content (both lignin and carbohydrate derivatives), as the water and ethanol contents were similar (Table S3).

Adding the fibre-forming PVA during dope preparation did not increase the viscosity substantially (Figure S6a) but made the viscosity shear rate dependent. A maximum viscosity at shear rates of 10-100 s^{-1} was observed for the spinning dopes.

Experiments at constant shear showed that the peak maximum was due to two competing processes, a viscosity increase over time related to a strengthening of the PVA network ("gelation") in the presence of the ionic liquid, responsible for increases in viscosity over time, and shear thinning, the latter being prominent at high shear rates.

We found in our previous study that extending dope preparation time and the associated increase in dope viscosity could be used to improve fibre spinning.[1] Indeed, the data show that higher viscosity dopes produced lignin PVA fibres with larger diameters (Figure S7) and single fibres with larger diameters are easier to handle manually due to the higher breaking force they can withstand, all else being comparable. Another factor affecting fibre diameter was the polymer loading.

Overall, the average viscosity increase (without shear thinning and gelation) was related to PVA content, lignin content and the gelation time. The dope with the highest PVA content and the longest gelation time prepared from the black liquor with high lignin loading, Dope 40-75% (6 h), had the highest shear viscosity, as shown in Figure S6b.

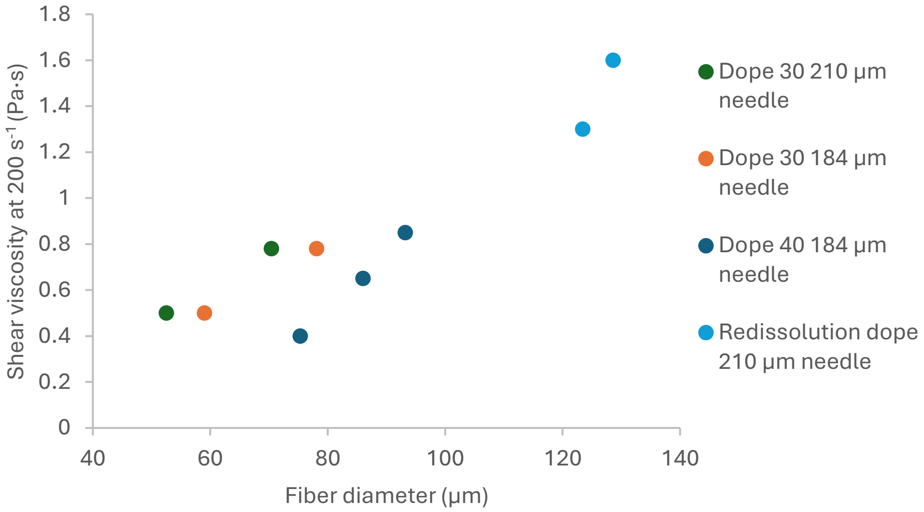


Figure S7: Correlation between the diameter of lignin PVA fibres and the shear viscosity at 200 s^{-1}. Eucalyptus lignin was extracted into [DMBA][HSO_4] water mixtures with 30% and 40% biomass loading. Data for redissolution experiments were extracted from Yang et al., 2023.[1]

Table S4: Data used for correlation in Figure S7 that are not in the main manuscript.

Biomass loading (%)	Dope preparation time (h)	Lignin PVA ratio	Needle I.D. (μm)	Fibre diameter (μm)	Tensile Strength (MPa)	Young's Modulus (GPa)	Strain at break (%)	Estimated carbon yield (%)
30	1	3:1	210	52.5 ± 3.9	41.4 ± 2.7	5.1 ± 0.1	0.9 ± 0.1	
30	6	3:1	210	70.4 ± 2.7	45.5 ± 1.4	5.2 ± 0.0	1.0 ± 0.0	

Table S5: Data used to correlate shear viscosity at 200 s^{-1} with fibre diameter.

Biomass loading (%)	Dope preparation time (h)	lignin to PVA ratio in dope (%)	Polymer loading (%)	Fibre diameter μm	Shear viscosity Pa·s
30	1	75/25	9.1	52.5	0.50
30	6	75/25	9.1	70.4	0.78
30	1	75/25	9.1	59.0	0.50
30	6	75/25	9.1	78.1	0.78
40	1	75/25	10.4	86.0	0.65
40	6	75/25	10.4	93.2	0.85
40	6	82.5/17.5	9.6	75.3	0.40
From lignin powder[1]	1	75/25	13.8	123.4	1.3
From lignin powder[1]	1	82.5/17.5	13.8	128.6	1.6

5. Additional SEM images of lignin PVA fibres

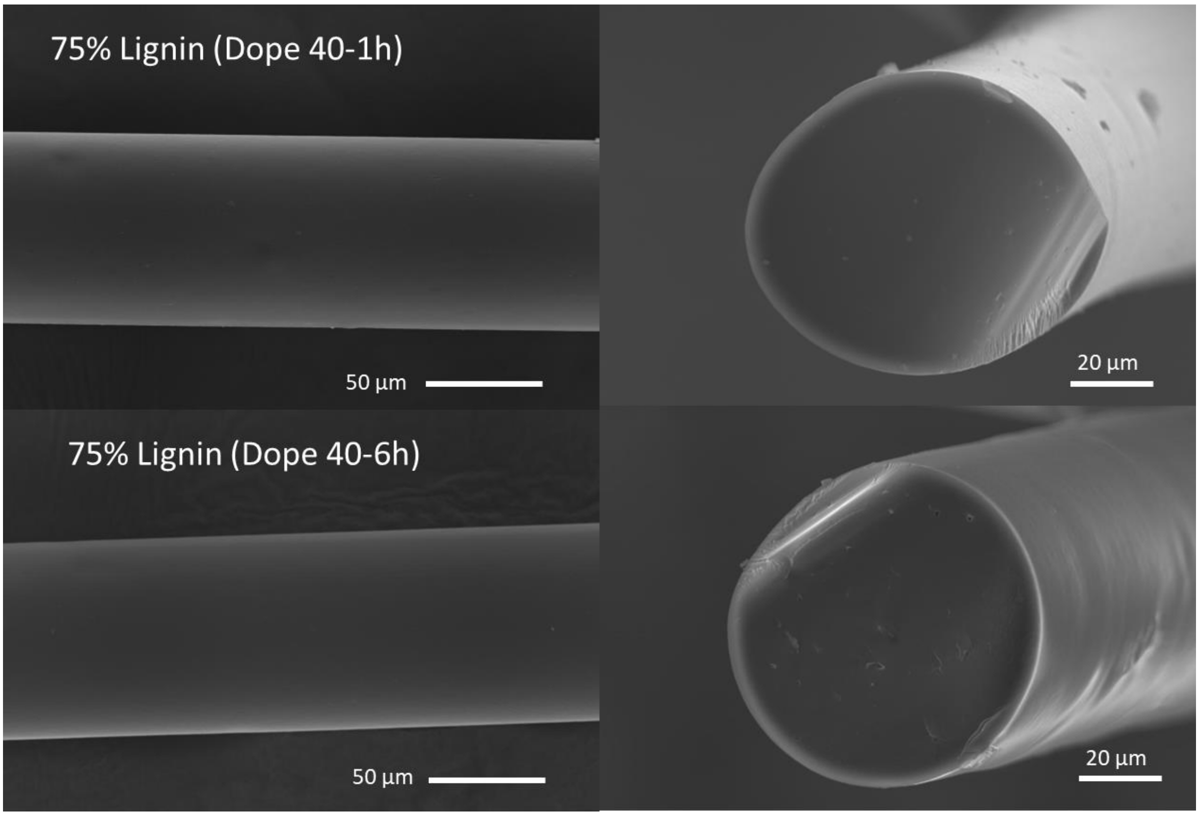


Figure S8: Additional SEM images of lignin PVA fibres prepared using ionosolv black liquors.

Table S6: Coagulated fibre yield

	Foil starting weight, g	**Weight of extruded dope, g**	**Oven-dried weight with foil, g**	**Oven-dried lignin/PVA fibre weight, g**	**Oven-dry yield, %**
Sample 1	0.1513	0.0330	0.1814	0.0301	91.2
Sample 2	0.1354	0.0218	0.1549	0.0195	89.4
Sample 3	0.1401	0.0176	0.1563	0.0162	91.9
Sample 4	0.1465	0.0181	0.1625	0.0160	88.3
Sample 5	0.1477	0.0226	0.1683	0.0206	91.0
				Average	90.4%
				Standard error of the mean	±0.6%

6. Additional SEM images of carbonised fibres

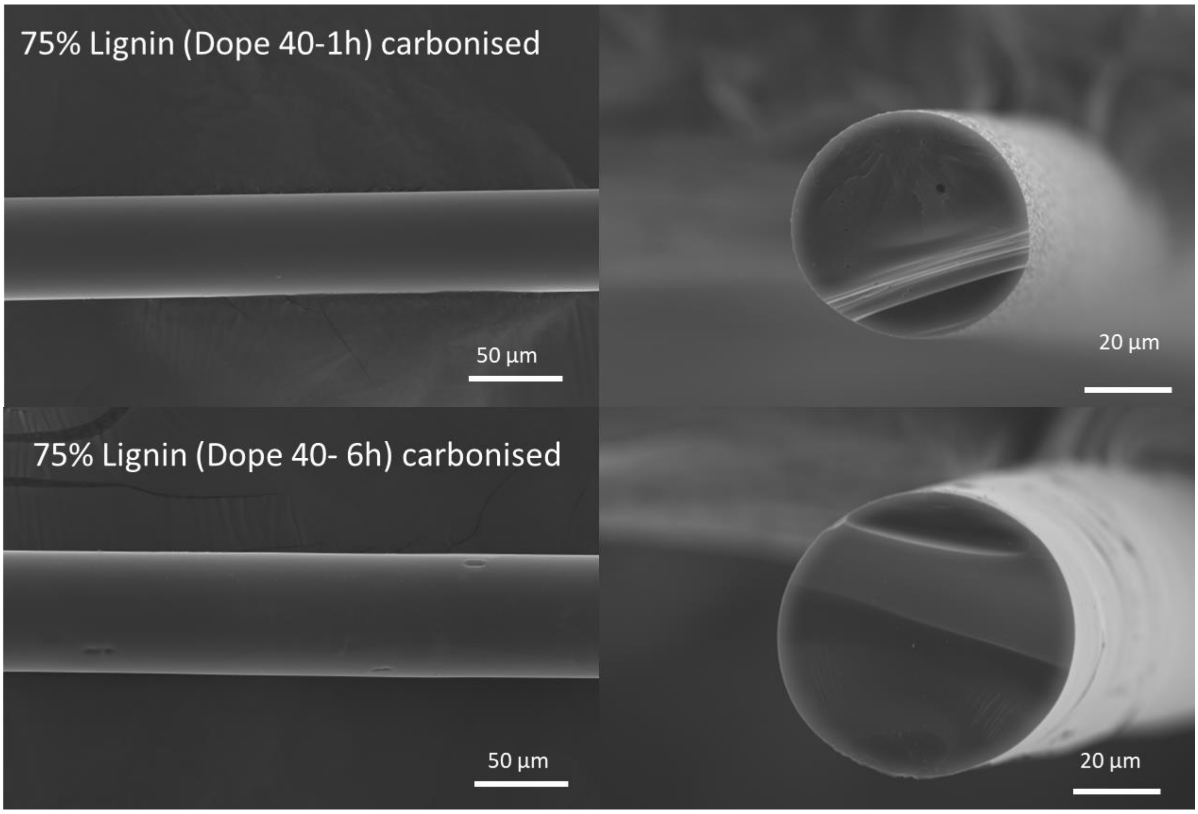


Figure S9: SEM images of carbonised lignin PVA fibres generated by integrated spinning. Dopes were prepared for 1 h or 6 h from ionosolv black liquors prepared with 40% biomass loading, stabilised in air and carbonised at 1000°C.

7. Detailed methods for LCA and TEA modelling

For both TEA and LCA, a mass flow rate of 100 kg/h feed biomass, a small-scale operating plant with a 20-year design life and 90% plant efficiency was used to conduct all process mass and energy balances, as well as environmental and cost-related data.[2] Ratios and percentages were utilised in accounting for mass flows across the different units (Figure S10 and Figure S11). Energy and/or electricity requirements for process operations of the different units were calculated using standard engineering principles and manufacturer data. All equipment was sized based on flow parameters for each unit. For the life cycle inventory, the equipment sizes (e.g., volume) were used to estimate the materials of construction (e.g., stainless steel) which was used in accounting for the equipment embodied burden. The 20-year design life was applied to all equipment and infrastructure within the plant.

7.1. Life cycle inventory

The life cycle inventory (LCI) consists of all data associated with the production of lignin carbon within the specified system boundary. To build the LCI, all materials within the primary units including feedstock, reagents, unit equipment etc. process energy requirement and energy to produce all consumables and emissions from the process were accounted for.[33]The foreground data was based on laboratory experiments for the IS method described in this paper, the RS process described by Yang et al,[1] and literature sources.[4, 5] Background information consisting of all secondary data including energy production, equipment materials of construction and other embodied burden was obtained from the Ecoinvent database via the SimaPro 9.4.0.2 platform.[6]

A streamlined approach was used in this assessment, therefore, some of the auxiliary processes (e.g., pulp treatment, storage for lignin precursor in the RS method, and land area required for personnel building or equipment spaces) were not included in the assessment. Credit from co-products/by-products such as unbleached pulp and organic volatiles was allocated to specific units. For example, the integrated spinning conducted lignin extraction in the fractionation stage, dope formation and spinning (lignin-fibre production), in this case, credits from distillates including furfural and acetic acid were calculated within the spinning unit. Likewise, the recovery of thermal energy was not captured, and the burden of released gas was allocated to the specific unit. Key inventory data are shown in Table S7 and Table S8.

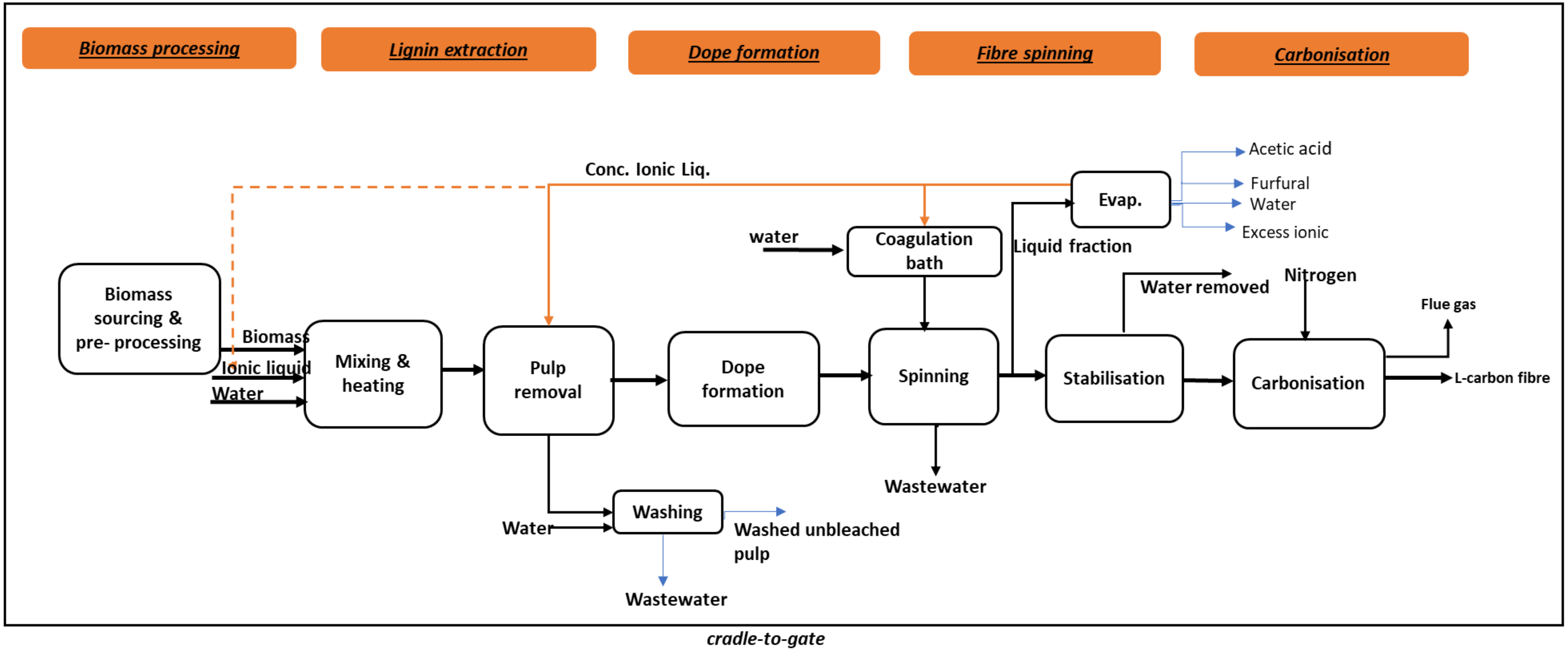
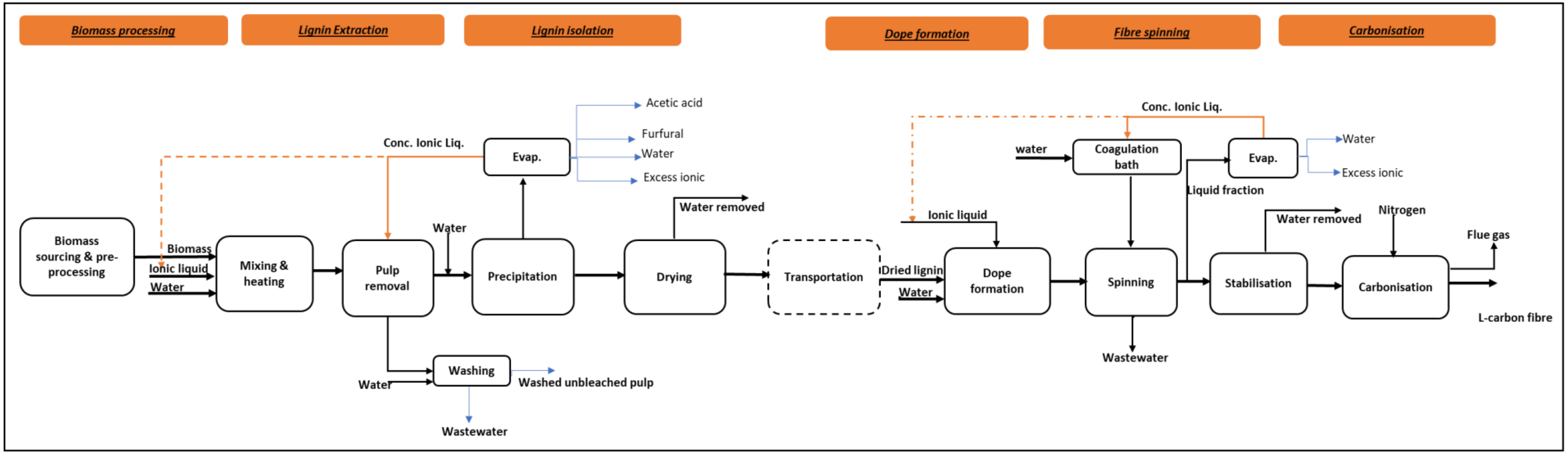


Figure S10: Cradle-to-gate process flow for lignin carbon fibre production via Integrated fibre spinning



cradle-to-gate

Figure S11: Cradle-to-gate process flow for lignin carbon fibre production via Redissolution fibre spinning

Table S7: Inventory for integrated spinning

Process Stage	Materials/solvents	Consumables	Energy	Equipment MoC
		kg/FU	MJ/FU	Kg/FU
Biomass processing			4.35	0.001
Lignin extraction	Ionic liquid (IL)	2.51	26.75	0.066
	Process water	0.6		
	Wastewater	2.38		
	Co-product pulp	3.08		
Dope formation	PVA	0.5	2.3	0.022
Fibre spinning (includes IL recovery)	Furfural	0.37	20.8	0.016
	Acetic acid	0.22		
	Wastewater	1.67		
	Process water	10.01		
	Recycled IL	2.49		
Carbonisation	Nitrogen	0.0018	87.0	0.003

Table S8: Inventory for redissolution spinning

Process Stage	Materials/solvents	Consumables	Energy	Equipment MoC
		kg/FU	MJ/FU	kg/FU
Biomass processing			4.49	0.001
Lignin extraction	Ionic liquid (IL)	2.58	27.49	0.02
	Process water	0.6		
	Wastewater	2.45		
	Co-product pulp	3.17		
Lignin isolation (includes IL recovery)	Process water	23.5	74.35	0.02
	Furfural	0.38		
	Acetic acid	0.22		
	Wastewater	18.3		
	Waste IL	1.7		
Dope formation	PVA	0.5	1.10	0.39
	Water	1.0		
	IL	0.7		
Fibre spinning (includes IL recovery)	Process water	19.5	10.6	0.02
	IL	0.1		
Carbonisation	Nitrogen	0.002	88.02	0.004
Total				

7.2. Life cycle impact assessment

The life cycle impact assessment (LCIA) stage was used to translate the list of items from the LCI (mainly input and output data such as emissions, wastes, products, and by-products) into different environmental impact indicators.[7]This starts by estimating the burdens to the environment associated with the emission of individual chemical species, which are further aggregated into environmentally functional groups referred to as Impact categories. A generic equation for calculating impact using inventory data and generic characterisation factors in the LCIA stage is shown in Equation 23.[98]The 2016 ReCiPe Midpoint (M) Hierarchist (H) (1.02) impact assessment method was employed to calculate the impact. This is a default globally recognised impact assessment method,[9] and closely linked to inventory data for the LCA, and sources of environmental impact, making it easier to verify with lower uncertainty.[10]

$$Category\ Indicator = \sum\nolimits_{s} (\text{Characterisation factor (s)} * Emission\ Inventory\ (s)) \qquad Eq. 23$$

where **s** represents the chemical species, and the respective characterisation factors (specific contribution to the impact category) are available in the literature and databases.

7.3. Cost modelling

For the IS and RS lignin production methods, the economic assessment started with cost modelling which was also based on data related to all the process stages, initial investment, labour, materials cost etc. In general, two main cost categories including the fixed and variable costs are considered in the cost modelling of any engineering system. The operating or variable cost is calculated on an annual basis. The capital cost is annualised and added to the operating cost. The traded product value is calculated on an annual basis. The difference between the product value and the total cost, both on an annual basis, gives the economic margin of system.[11, 12] A simple generic cost model is shown in Eq. 24.

$$C_t = C_f + C_v \qquad Eq.\ 24$$

The fixed and operating costs can be calculated using Eq. 25 and Eq. 26, respectively.

$$C_f = C_l + C_o + C_c \qquad Eq.\ 25$$

$$C_v = C_m + C_{cn} + C_e \qquad Eq.\ 26$$

Where $C_l,\ C_o\ and\ C_c$ are the labour cost, overhead cost, and capital cost while $C_m, C_{cn}\ and\ C_e$ represent the costs of material, consumable and energy.

For the operating costs C_v, the specific quantity of material or energy is multiplied by the cost per unit of that item (adjusted to reflect current market price),[13] for example, the energy cost of the whole fractionation stage can be expressed as Eq. 27.

$$\text{C,}_{Ef} = E_f * C_i \qquad Eq.\ 27$$

E_f is the total electricity burden of the fractionation unit and C_i is the cost per unit of electricity. For the fixed capital investment C_f, the equipment data from the inventory is used to determine the installed equipment cost (adjusted to reflect the current year).[2, 14] All revenues from sales of co-products and by-products were calculated, likewise their environmental benefit.

Table 9: Cost data for utilities

Cost Input for operational expenditure					
Utilities	***Price***	***unit***	***Reference year***	***Conversion factor***	***Adjusted price (2024)***
Electricity (UK country mix)	0.227	GBP/kWh	2024	1.26	0.286
Natural gas	0.040	GBP/kWh	2024	1.26	0.0500
Labour (UK)	14.2	GBP/h	2023	1.26	17.89
Transport Energy	0.38	GBP/mile	2023	1.26	0.479

Table 10: Cost data for consumables

Cost Input for Consumables					
Item	***Price***	***Unit***	***Reference year***	***Conversion factor***	***Adjusted price (2024)***
Biomass	0.09	\$/kg	2024	1	0.09
Ionic liquid ([DMBA][HSO_4])	0.535	\$/kg	2023	1	0.535
Process water	0.004	\$/kg	2019	1.557	0.005450
PVA	2.68	\$/kg	2024	1	2.68
Nitrogen	0.060	\$/L	2005	2.016	0.1210

Table 11: Cost data for products and co-products

Products					
Lignin- carbon fibre	16.5	kg/h		25	\$/kg
Cost/Revenue from co-products/by-products					
Acetic acid	0.604	\$/kg	2024	1	0.604
Furfural	1.83	\$/kg	2024	1	1.83
Cellulose pulp	0.700	\$/kg	2024	1	0.7
Wastewater	0.0004	\$/kg	2019	1.557	0.0006892

7.4. Effect of IL recycling on LCA of lignin carbon fibre production

The impact of ionic liquid recycling on the GWP (kgCO_2-eq) of carbon fibre production via redissolution spinning is shown in Figure S12 and Figure S13 which highlights the relationship between the number of ionic liquid reuses and the GWP impact and production cost respectively. A similar trend was observed for integrated spinning.

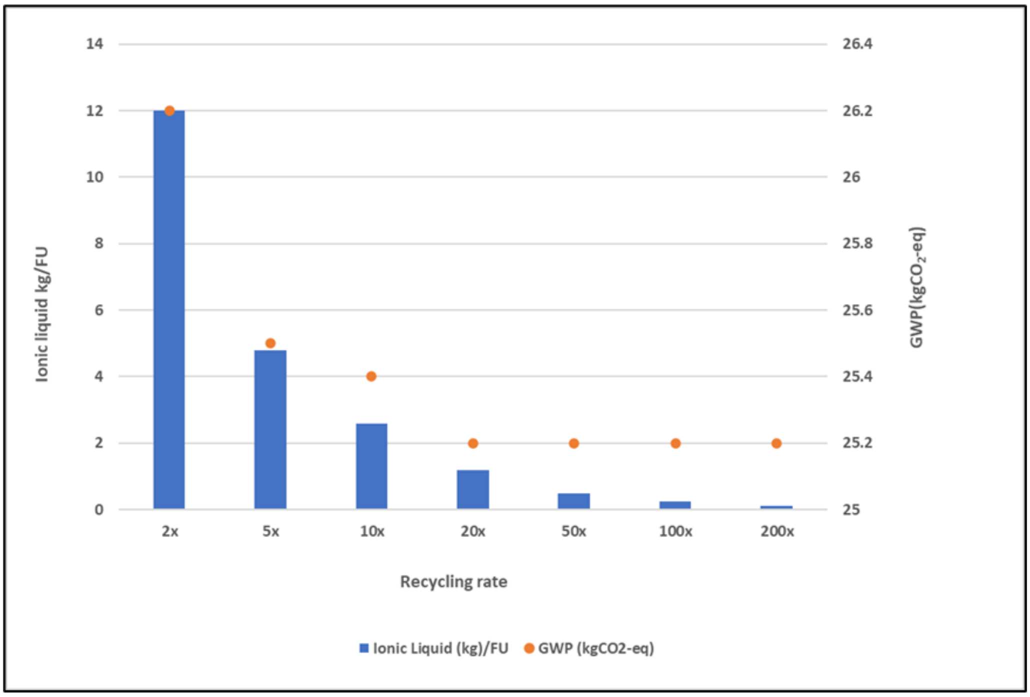


Figure S12: Impact of ionic liquid recycling the global warming potential of carbon fibre production using redissolution spinning

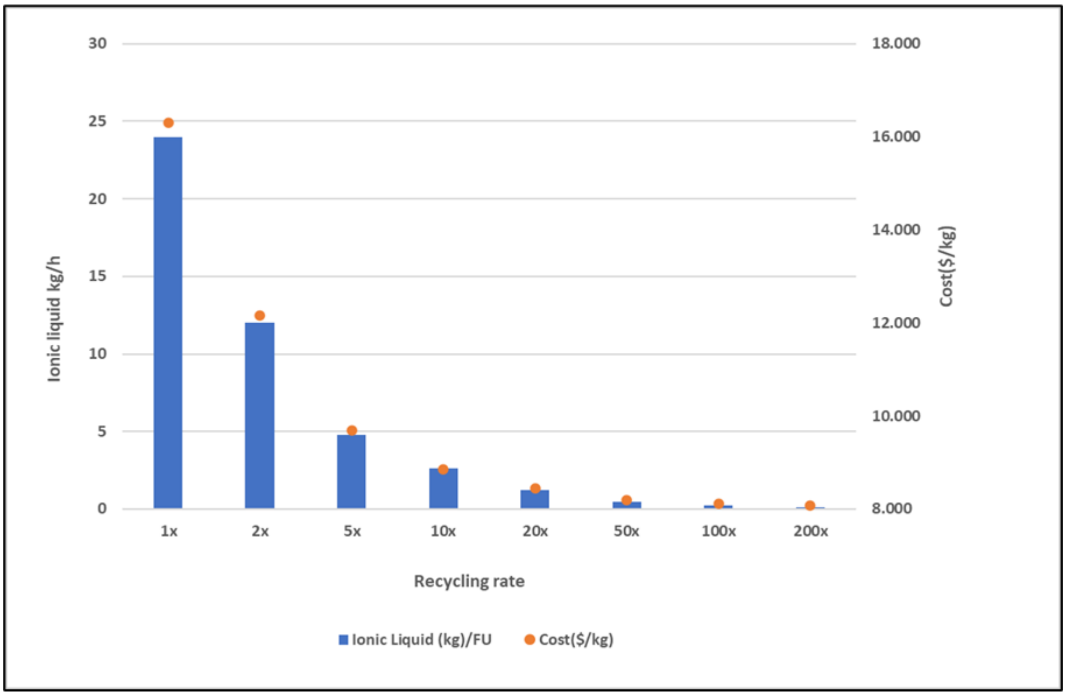


Figure S13: Impact of ionic liquid recycling on carbon fibre cost from redissolution spinning

7.5. Effect of Carbonisation variables on LCA of lignin carbon fibre production

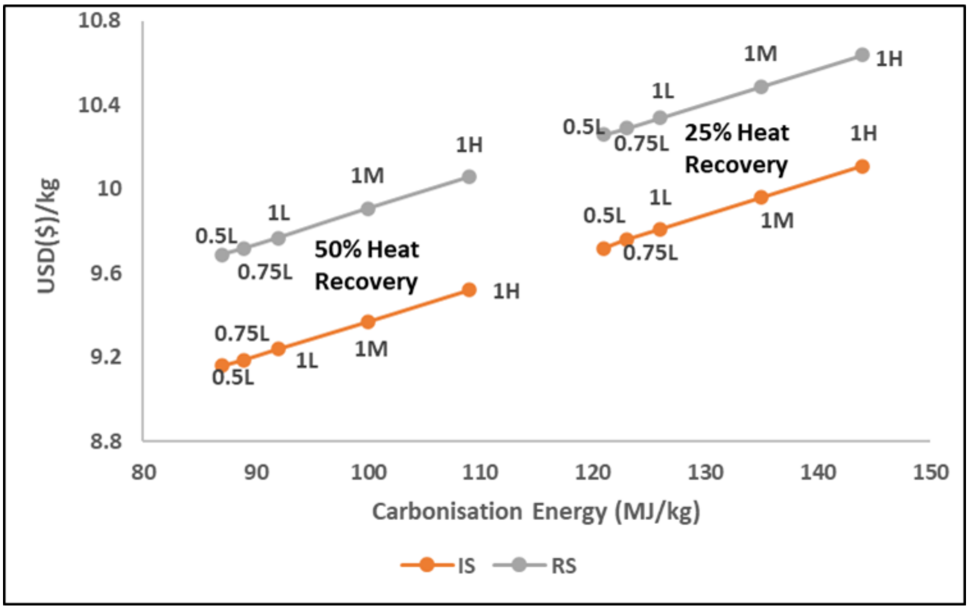


Figure S14: Sensitivity analysis exploring LCF cost against variation of carbonisation stage energy, based on residence times and varying levels of heat recovery and losses. The data points relate to carbonisation residence time (1= 60 mins, 0.75=45 mins and 0.5=30 mins) and heat loss coefficient (low (L), medium (M), high (H)).

7.6. Sensitivity analysis plots for carbon fibre via redissolution spinning

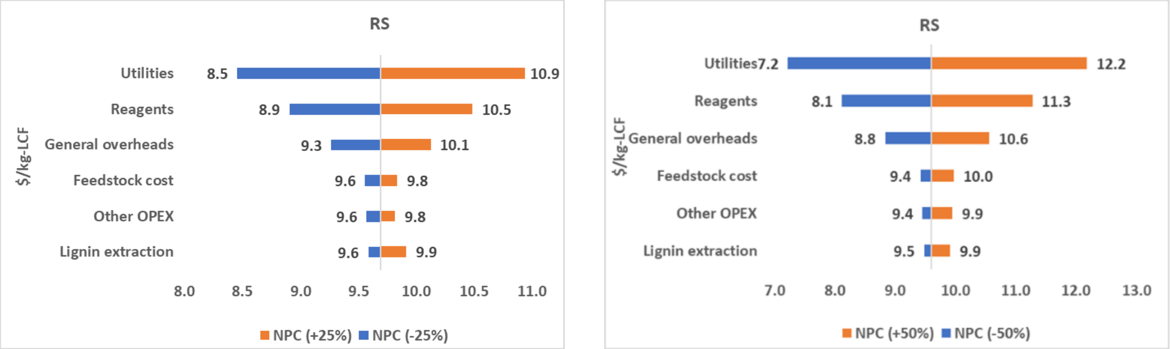


Figure S15: Cost sensitivity scenario for redissolution spinning

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