# Forging The Blades of the Future With Composite Materials With Circular, Safe and Sustainable Design

UNIVERSITY OF LIMERICK OLLSCOIL LUIMNIGH | Bernal Institute

BLADE2CIRC

RW 26

## Deliverable 1.3: Report on the Carbon Fibres Properties

Carbon fibres are essential for lightweight, high-performance applications in wind energy, automotive, and aerospace sectors; however, conventional fibres are predominantly derived from fossil-based precursors, resulting in energy-intensive production and limited sustainability. In the context of the Blade2Circ project, Deliverable 1.3 focuses on evaluating the properties of carbon fibres developed from lignin, an abundant and renewable by-product of the paper industry, as a greener alternative for wind turbine components. Lignin-derived carbon fibres were successfully produced, upscaled and systematically characterised to determine their surface morphology, mechanical performance, and wettability, providing a comprehensive assessment of their suitability for composite applications.

### WHY Lignin?

- Abundant
- Renewable
- Low-cost Waste
- Sustainable Future

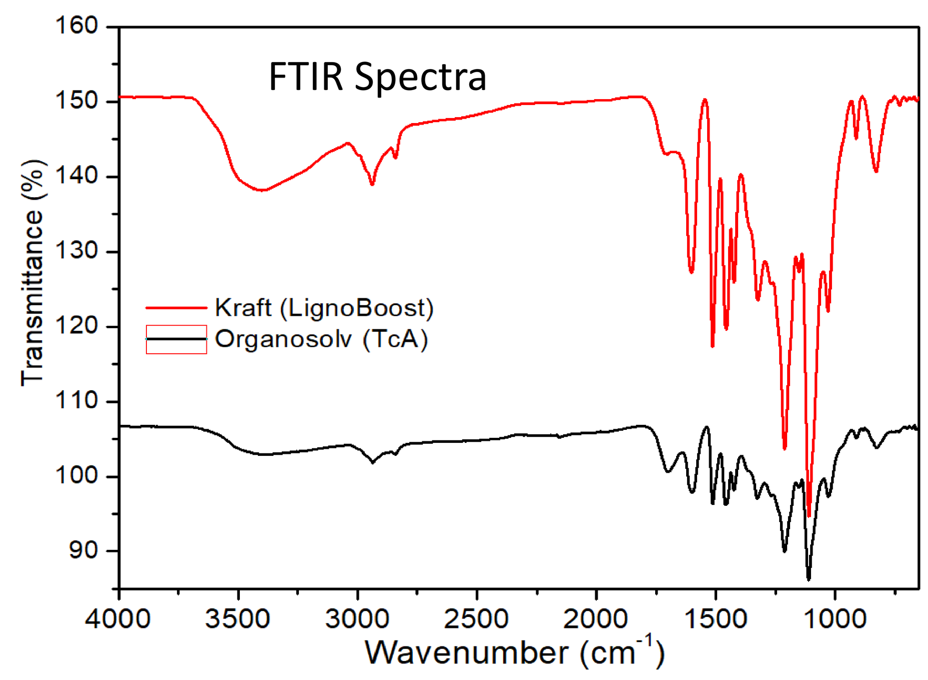


*Figure 1: FTIR Spectra showing heterogeneity of Kraft lignin compared to Organosolv lignin*

**Table 1: Lignin Selection Criteria**

| Lignin Type | Advantages | Disadvantages | Global Production |
|---|---|---|---|
| **Organosolv** | Cleaner, homogeneous, superior fibre performance | Costly, complex extraction | ~3,000 t/yr |
| **Kraft** | Low-cost, scalable from pulp mills | Heterogeneous, lower performance | ~55 Mt/yr |

### Surface Morphology

- Lignin-derived carbon fibres exhibited smooth, uniform surfaces with minimal defects after thermal treatment, indicating strong structural integrity.
- Finer fibre diameters showed fewer defects and improved structural uniformity, supporting better fibre-matrix bonding and composite performance.

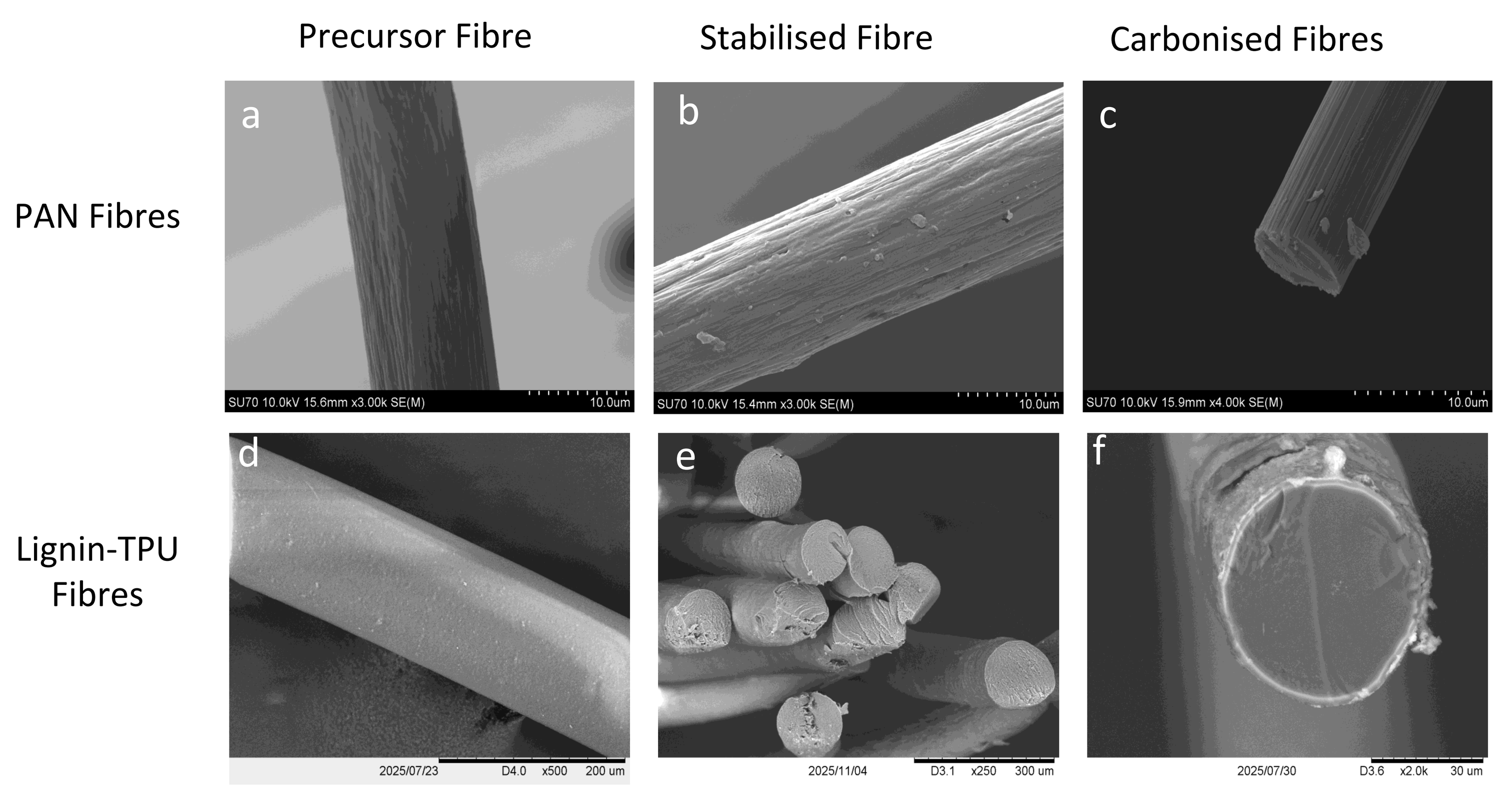


*Figure 3: SEM micrographs showing: (a-c) PAN fibres; (d-f) lignin-TPU fibres, before and after thermal stabilisation and carbonisation treatments.*

### Conclusion & Future Outlook

- Bio-based (Lignin) carbon fibres offer a sustainable alternative to PAN.
- Organosolv lignin gives higher strength (~1.25 GPa) and modulus (~275 GPa), while Kraft lignin is more scalable.
- Lignin fibres show improved wettability, enhancing fibre-matrix bonding.
- Properties depend on lignin type, fibre diameter, and processing conditions.
- Future efforts will focus on optimisation of precursor chemistry and processing parameters to improve scalability, fibre uniformity, structural consistency, and enhance mechanical performance.

### Lignin Derived Carbon Fibres Development

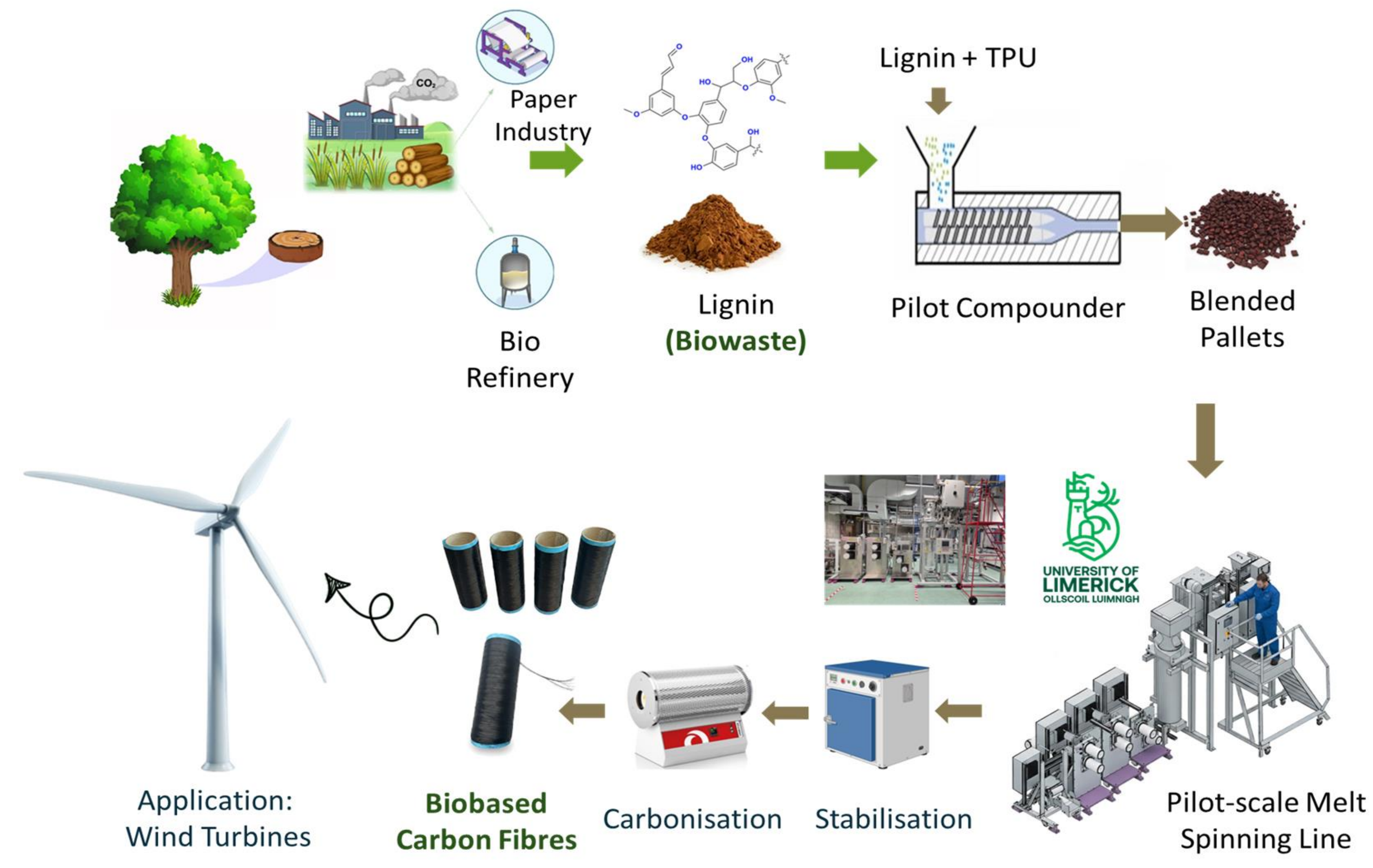


*Figure 2: Flow Chart of Development of Lignin-derived Carbon Fibres.*

### Mechanical Performance

- Organosolv carbon fibres showed superior mechanical properties vs. Kraft-based.
- UV/TDI surface treatment enhanced modulus.
- Smaller fibre diameters increased tensile strength and stiffness.

**Tensile Properties of Lignin-derived Carbon Fibres**

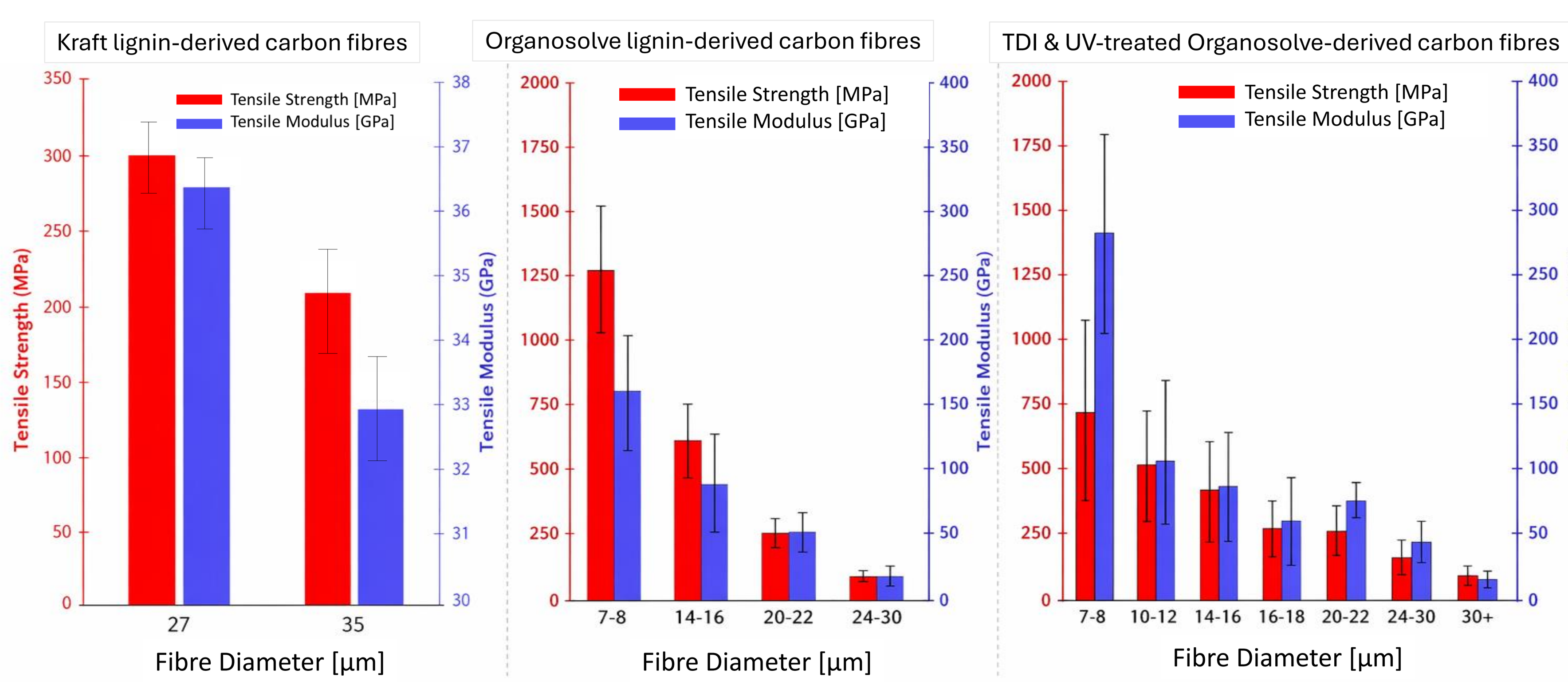


*Figure 4: Single-fibre tensile test results (ASTM C1557) for Kraft- and Organosolv-derived carbon fibres before and after TDI and UV treatments (Vaughan et al. 2025).*

### Wettability Performance

- Lignin-based fibres showed improved wettability compared with PAN-derived fibres.
- This improved surface wetting can enhance interfacial bonding in composite materials.

**Contact Angle of Fibers at Different Processing Stages**

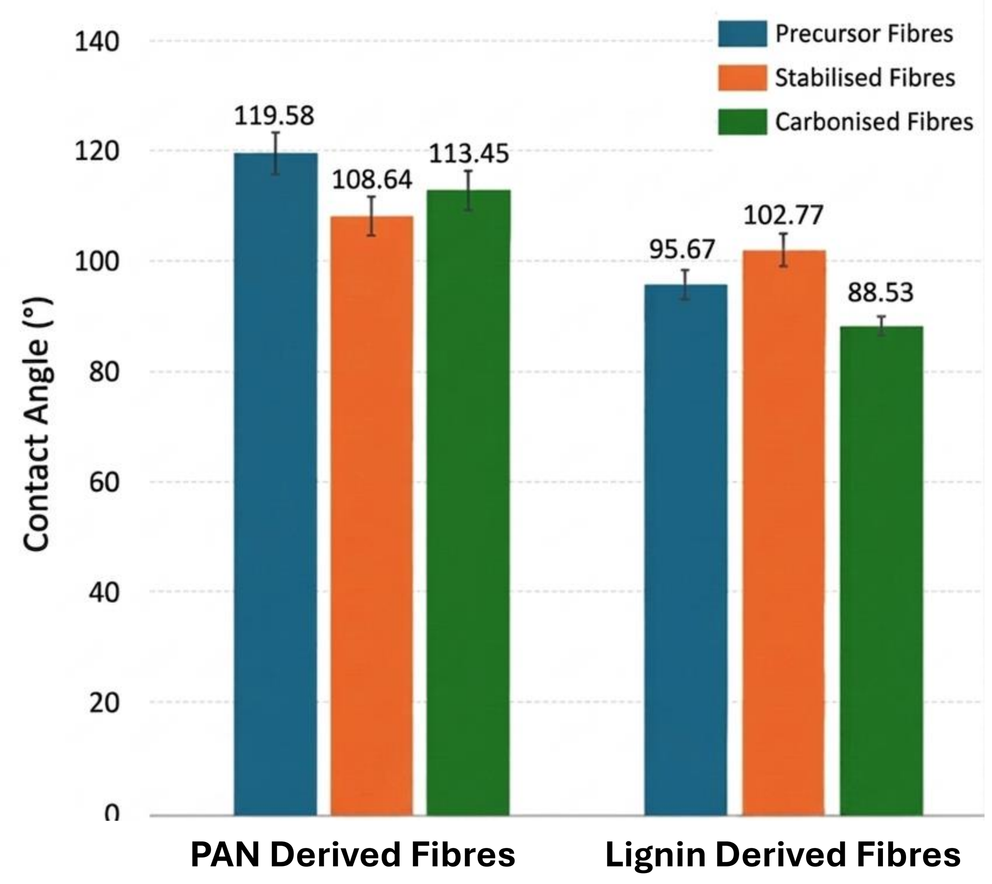


*Figure 5: Water contact angle measurements of PAN- and lignin-derived carbon fibres.*

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