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How can we decarbonize carbon fiber toward NetZero scenarios?

Yorick Richard · Materials Science and Engineering · Laidlaw Scholar · LPAC, EPFL · supervised by Dr Martyn D. Wakeman

THE ANSWER

The industry

The carbon fiber industry is small in volume and high in value, and aerospace and wind energy depend on it. The world produces about 105 kt of fiber a year; the energy transition needs three to eight times as much by 2050, depending on the pathway. Producing one kilogram emits 15 to 80 kg of CO_2e.

The model

Cutting the footprint of each kilogram is not enough if demand multiplies at the same time. A credible roadmap has to model both at once: how much fiber the world will need, how clean each kilogram can get — bio-based precursors instead of petroleum, cleaner electricity, and more fiber coming back at end of life. That is what we are modeling.

ONE ROADMAP TO 2050
2020 → 2050, the NetZero pathway, one of 5 688 we modeled

Fiber the world needs per year · 105 → 472 kt	**×4.5**
CO_2e per kilogram of fiber · about 20 kg today → 4 kg	**−80 %**
Emissions before capture · peak 4 571 kt/yr in 2033 → 2 297 kt/yr by 2050	**−50 %** from peak

This pathway does not reach zero emissions. Until the early 2030s, demand grows faster than the footprint per kilogram falls, so total emissions keep climbing. The CO_2e still emitted in 2050 would have to be captured.

Proxy LCA intensities; SimaPro models in progress. The mechanism is robust, the numbers will move.

WHERE IT COMES FROM · WHERE IT GOES · WHAT COMES BACK

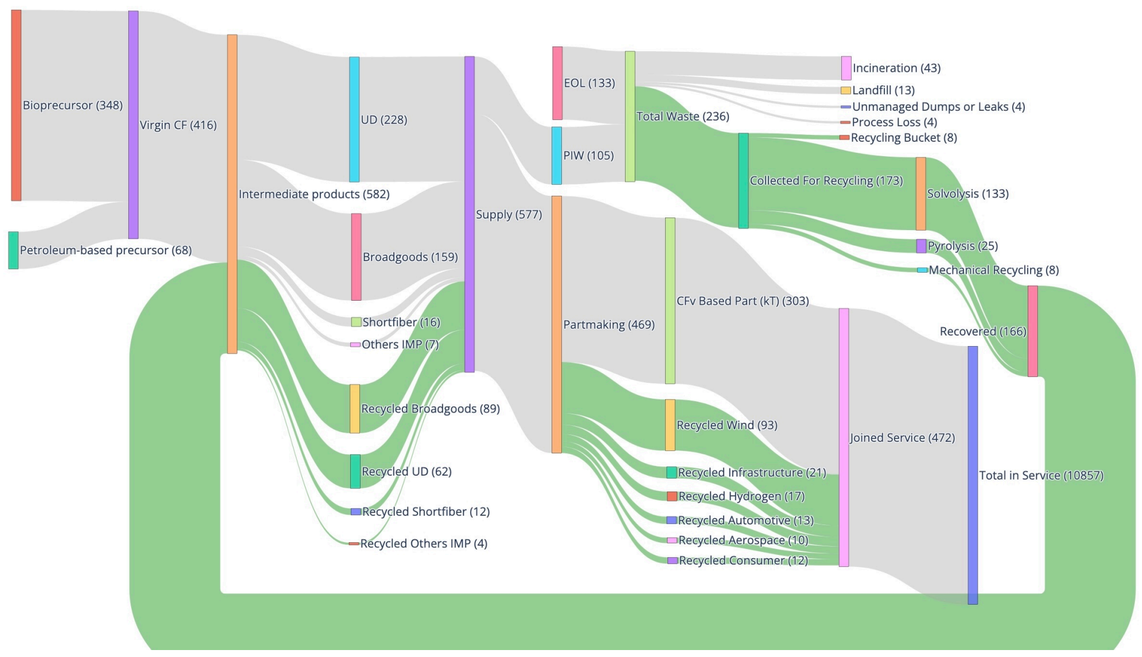

Fig. 1 Where every kilogram of carbon fiber comes from and goes in 2050, on the NetZero pathway: every technology at its best, on an essentially carbon-free grid.

WHAT I CHANGED

A kilo of recycled fiber is not a kilo

Recovered fiber comes back with lower strength, shorter fibers and less alignment, so it takes more of it to do the same job. The model I inherited treated a kilo of recycled fiber as a kilo of virgin fiber, one for one.

What I did

01 EVERY KILO CARRIES A PENALTY The penalty is how many kilos of recovered fiber it takes to do one virgin kilo's job. It depends on the recycling route and rises each time around the loop, and it is fixed when the part is built.

02 STRICTEST MARKET FIRST All recovered fiber enters a single pool. Aerospace is served first because its specifications are the tightest; what does not meet them cascades down to less demanding markets, and what no market can use waits in a buffer until recycling technology improves.

03 REBUILT THE ENGINE Because each year's parts lock in that year's recycling quality, the model can no longer solve 2020–2050 in a single pass: it now steps year by year.

EFFECTIVE CIRCULARITY IN 2050 (%)

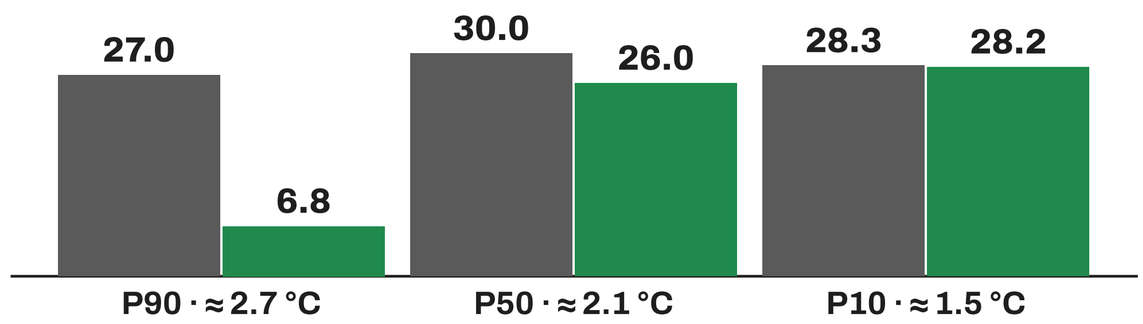

Fig. 2 How circular is the industry in 2050? These are three reference scenarios, roughly 2.7, 2.1 and 1.5 °C, not the NetZero case on the left.

CO_2e EMISSIONS PER YEAR IN kt

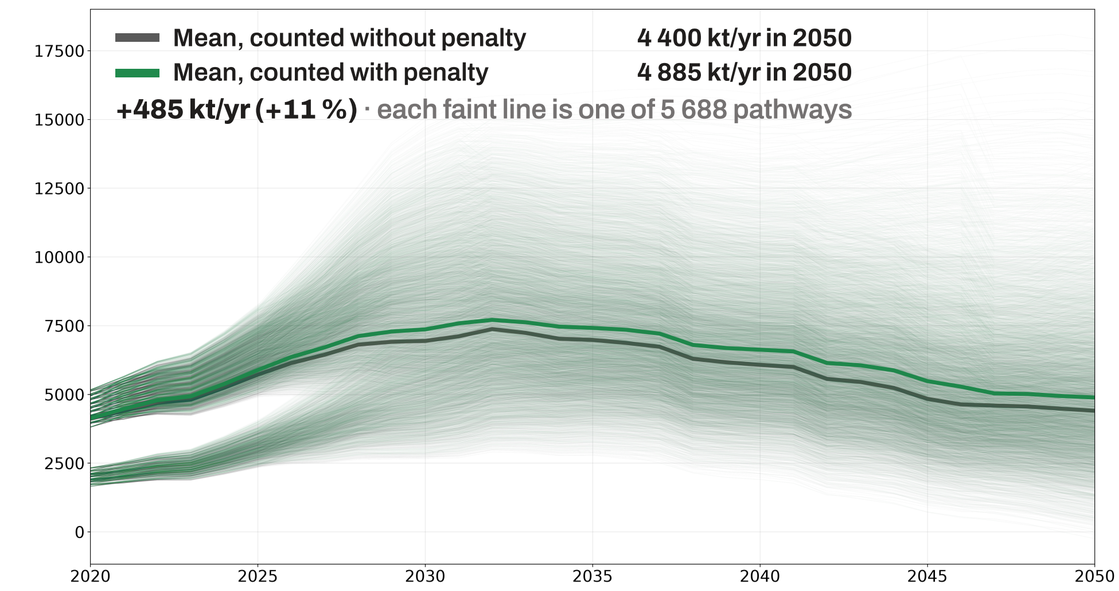

Fig. 3 Annual emissions across 5 688 pathways, with and without the penalty.

Bending the curve is possible. Zero needs capture.

On the NetZero pathway, demand grows 4.5-fold; cleaner processes cut 80 % per kilogram and recycling covers more than a quarter of what the world needs. Capture does the rest.

FUTURE WORK

- → **Replace the proxy intensities** with our own SimaPro life-cycle data.
- → **Finish the model and build the tools to explore it.**
- → **Run to 2080, not 2050.** Carbon fiber stays in service for decades.
- → **Take the finance and CAPEX modeling further**, so industry can weigh costs against emissions and analyze the trade-off.
- → **Adapt it to the plastics industry.**

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yorick.richard@epfl.ch

Model: EPFL LPAC NetZero2050
E4S. Scenario modelling of the carbon fiber industry in the transition to NetZero 2050. e4s.center
E4S. Re-wiring CAPEX and finance in circular value chains: a case study of advanced materials. e4s.center