

EXECUTIVE SUMMARY

The Future of Carbon Fiber Composites

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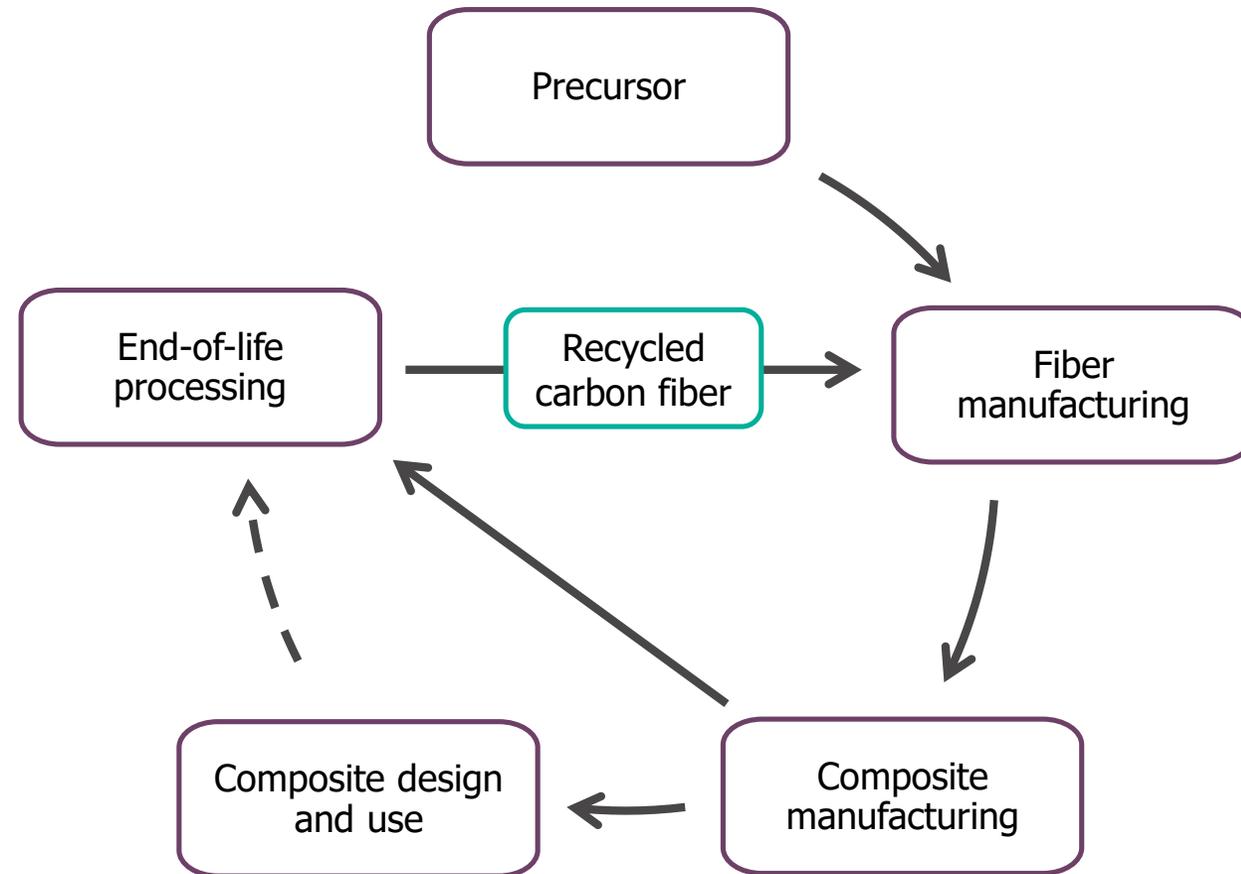
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EXECUTIVE SUMMARY

Fiber standardization and increased circularity will drive CFRP growth despite tough market conditions

The carbon fiber industry is currently facing three major changes: weakness in underlying markets, fiber standardization, and recycling. Recycling and standardization could be opportunities for the industry to form a circular economy, increase adoption, and diversify the CFRP value chain and in doing so create new demand for carbon fiber. However, both are potentially competitive threats to existing fiber producers, which have controlled the space.

Enabling fiber standardization and recycling of fibers is key to expanding the CFRP market. Standardization will be the key to enabling and expanding CF recycling into a more global and unified system. Recycled CF will expand the value of the market, not cannibalize existing applications for CFRPs and push adoption overall. With a broader value chain and opportunities for more companies to manufacture with CF, the number of companies and industries looking at CFRP as a new material option will expand.

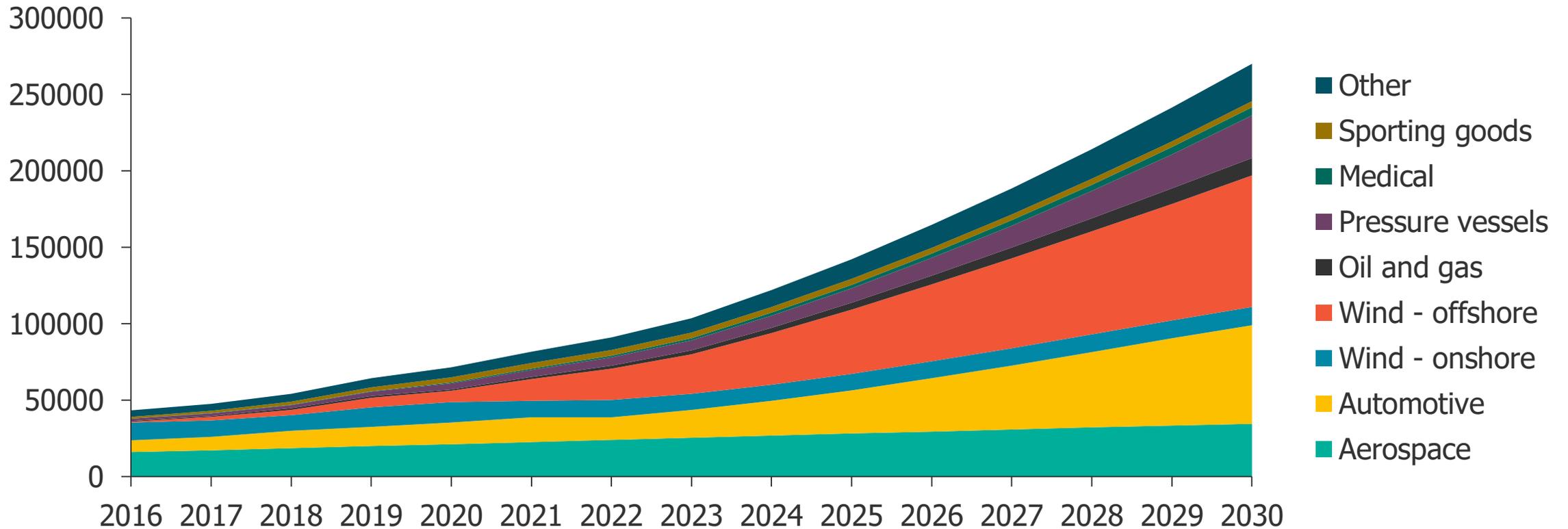


MARKET FORECAST

Weakness in aerospace and automotive demand reduces CF growth; demand to hit 264,000 tons in 2030

Carbon fiber market

MT fiber



Weakness in aerospace and automotive demand reduces CF growth; demand to hit 264,000 tons in 2030

Lux has substantially downgraded our growth outlook compared to our 2017 forecast.

- The biggest difference is in the aerospace sector. Our 2017 projections were overly aggressive on commercial airline deliveries and needed to be downgraded – even before the double impacts of the 737 Max production halt and the COVID-19 pandemic. With these extreme events, our forecast drops significantly (from 27,000 tons) to 21,000 tons in 2020 growing to just 35,000 tons in 2030 (as opposed to more than 45,000 tons in 2025). Consumption in 2020 could be substantially lower than shown in the graphic.
- The automotive industry has suffered as well since 2017; sales and profits were hit before COVID-19 and have taken a nosedive since. This has substantially delayed CF adoption, and our new forecast has the automotive space reaching 64,000 tons in 2030 – about five years later than predicted in our 2017 report.
- The previous forecast was directionally correct for wind, forecasting substantial increases in the growth of offshore wind, which appears to be on track. We have adjusted some of our forecasts and reduced overall consumption onshore, as adoption in certain components – like towers – was slower than predicted.
- The forecast for oil and gas remains dim, as continuously low oil prices make subsea exploration – where CF has the best use case – an uneconomical prospect.
- The pressure vessel forecast remains largely unchanged through 2025, but we expect strong growth from 2025 through 2030 as hydrogen demand picks up.

MARKET FORECAST

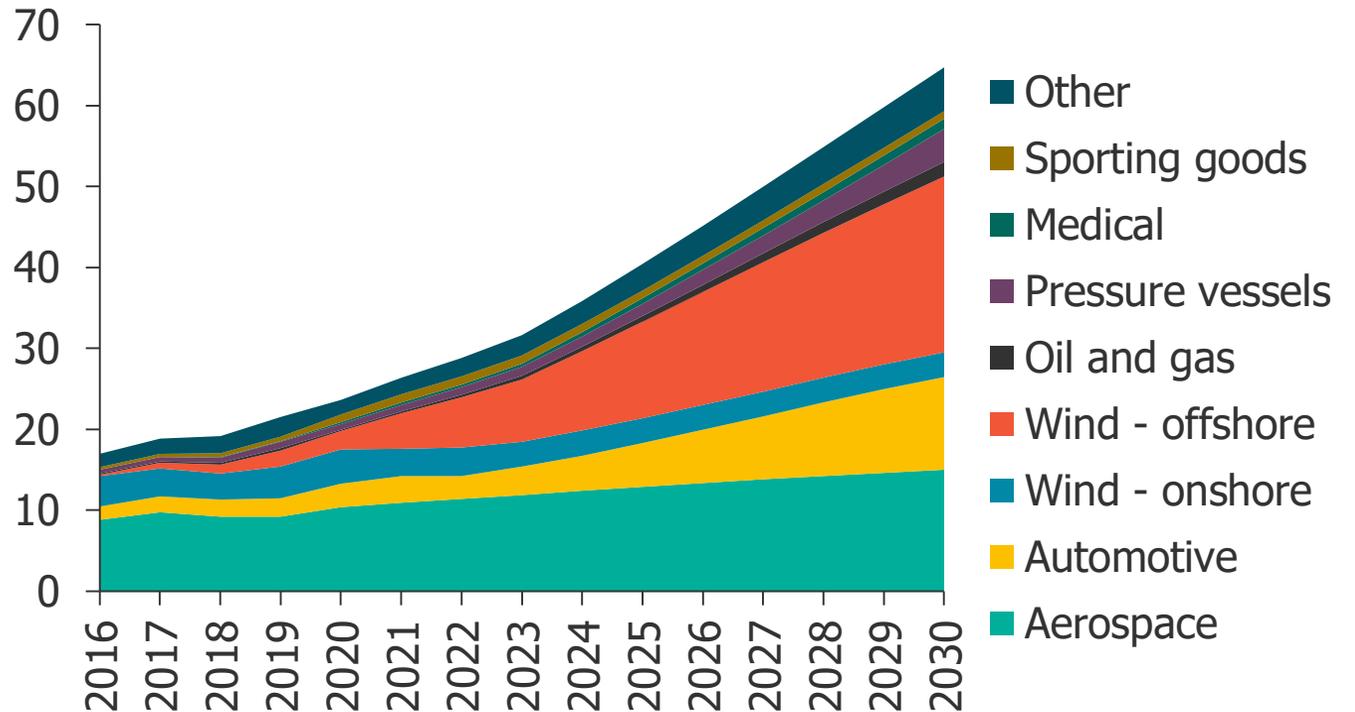
The market for CFRP will grow to \$64 billion by 2030

The CFRP market reflects the same underlying weakness as the CF demand – slower growth in the aerospace and automotive sectors weakens the overall demand space. This weakness sets the overall growth back around four to five years compared to our 2017 forecast, when we expected the CFRP market to reach the mid-\$65 billion range by around 2025.

As in 2017, we expect that the offshore wind sector will grow to be the largest demand center overall, as large blades incentivize stiff CFRP, and the cost reductions afforded by pultruded spar caps enable greater market penetration of cheaper components.

CFRP market forecast

\$ billions



This report focuses on innovations across four of the five main stages in the CFRP manufacturing process

We divide the CFRP space into five sections:

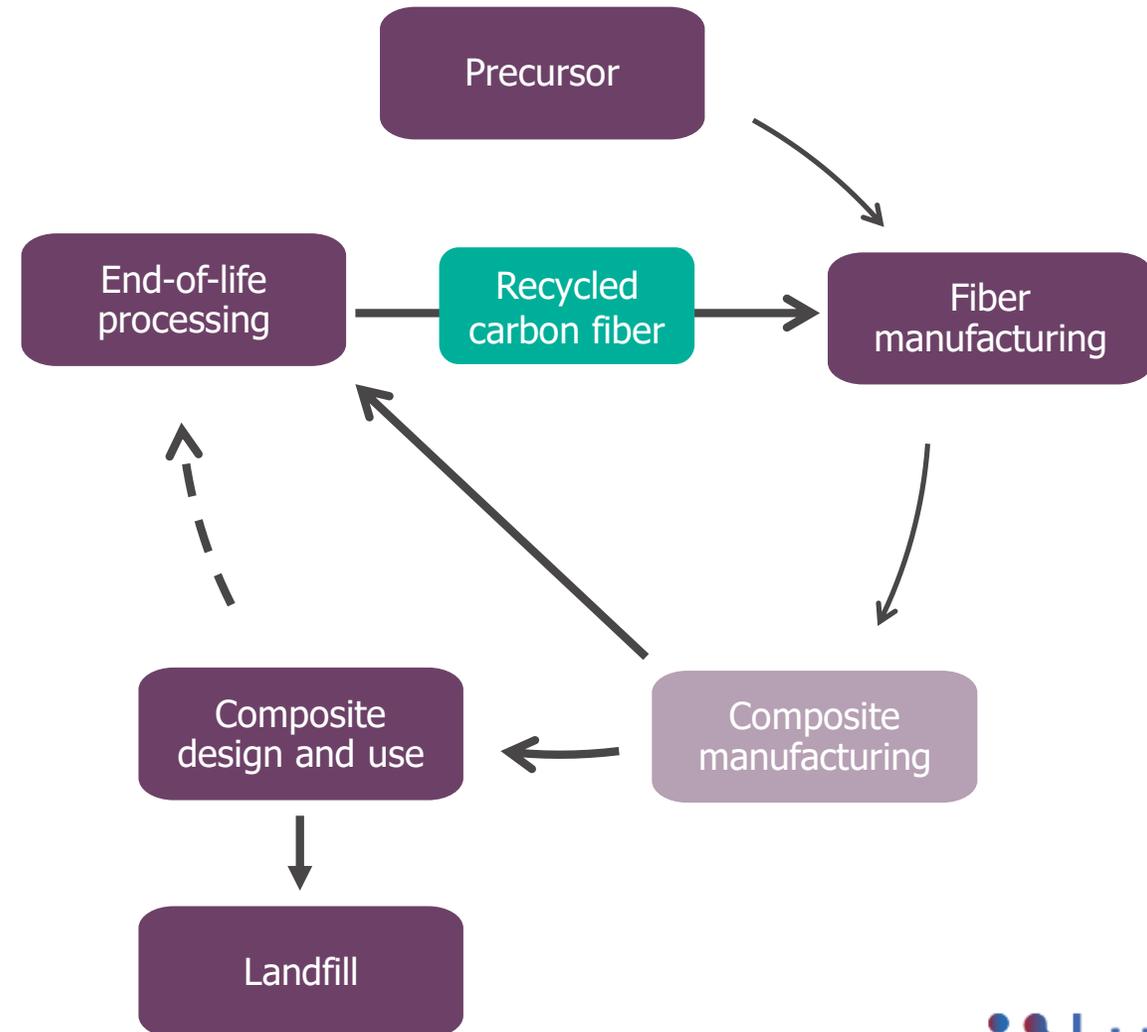
Precursor production: Polyacrylonitrile (PAN) is the most common precursor; however, there are several alternatives that we will analyze.

Fiber manufacturing: This varies depending on the precursor being used. The main issue is standardization of fibers, which can create opportunities for new players.

For information on **composite manufacturing**, see Lux's "[Composite Manufacturing Update 2018 Edition](#)" report.

Composite design and use: CFRP composite applications need to expand for broader adoption and increase in market size.

End of life: Currently, composite materials are disposed into landfills. However, CF is a valuable material, and CFRP needs to be recycled to recapture this value. The recycling also needs to grow beyond postindustrial waste to post-consumer waste recycling.



PRECURSORS

At least 90% of commercially available carbon fibers are PAN-based, and PAN will likely remain the default precursor for CFs

Polyacrylonitrile (PAN) is a synthetic, semicrystalline organic polymer resin with the linear formula $(C_3H_3N)_n$. Almost all PAN resins are copolymers made from mixtures of monomers, with acrylonitrile as the main monomer.

PAN fibers are the chemical precursor of high-quality carbon fiber. The vast majority of the world's carbon fiber is derived from PAN made using an ACN monomer of propylene and ammonia. ACN is polymerized into PAN by combining it with plasticized acrylic comonomers and a catalyst. This entire chemical production and conversion process is complex, expensive, and energy-intensive. Further, producing 1 kg of carbon fiber requires 2 kg of PAN, which gives PAN a conversion rate of just 50% to 55% – and a relatively large greenhouse gas footprint.

Most carbon fiber companies manufacture their own precursor using in-house technologies. Variables include the type of solvent, type and amounts of comonomers, and degrees of fiber shrinkage and stretching in the manufacturing process. Each company's recipe is differentiated and maintained as trade secret. As a result, users of CF need to invest a lot in initial evaluation and characterization, making changing CF grades costly. Overall, the lack of standardization and monopolization by CF companies discourage consumer companies from adopting CF, and if they do, then it is very difficult to change suppliers.

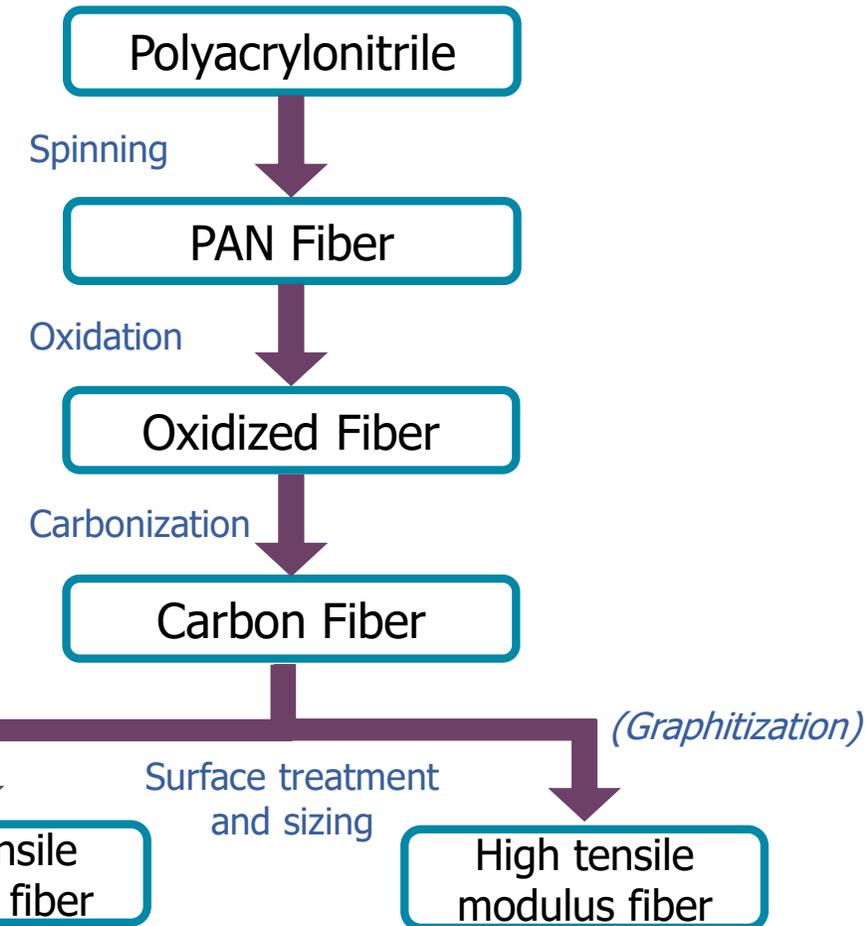
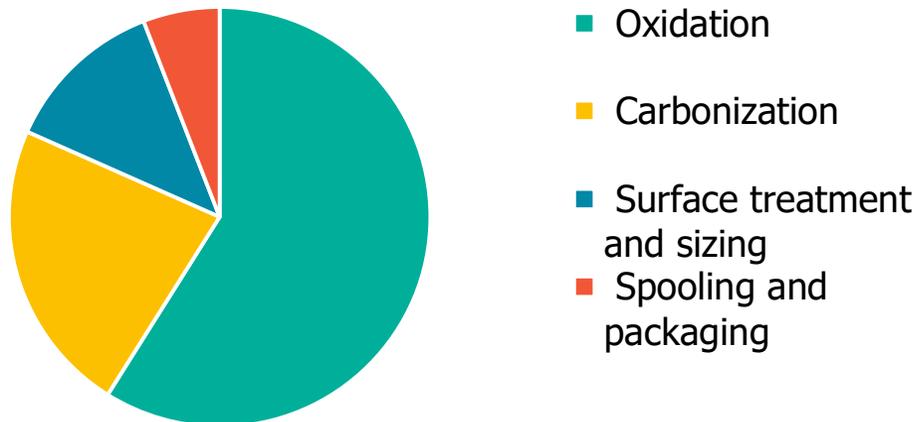
• **LUX TAKE: POSITIVE** PAN-based CFs have the ideal balance of tensile strength and modulus properties for many applications, which is directly related to the internal and external flaws and the crystal size, structure, and orientation within the fiber. Despite yield issues, PAN-based carbon fibers have the most efficient production method relative to other precursors; the energy required, additional chemicals, and wastage are relatively lower.

FIBER PRODUCTION

PAN fiber production is an expensive and energy-consuming method, but better than other precursors

The process for making carbon fibers is part chemical and part mechanical. The manufacture of PAN-based carbon fibers takes place in three major steps. The first step is spinning PAN polymer solution to create PAN precursor fibers. The second step is the oxidation of PAN precursor fibers through heat treatment (<300 °C); this is the most expensive and energy-consuming step. The third and final step carbonizes fibers (up to 1,500 °C), removing all noncarbon atoms and creating the final product, that is, the carbon fiber. With appropriate manufacturing techniques, it is possible to produce a combination of high mechanical strength fibers and high or low modulus.

Baseline costs for fiber production



Source: The Japan Carbon Fiber Manufacturers Association; adapted by Lux Research

Design for recyclability: End-of-life processing is no longer a “nice-to-have” but rather necessary for all materials

Aerospace

Aerospace is one of the only industries that can collect all of their waste and out-of-service parts and vehicles and recycle postindustrial and post-consumer waste streams to reclaim recycled carbon fibers. Aerospace composite producers do currently recycle postindustrial waste and theoretically could establish their own circular economies with very few barriers. The aerospace industry is committed to improving recycling.

Wind

For wind turbines, there is an increase in the use of hybrid composites with glass fibers and CF. While hybrid composites would enable wider adoption prospects for CF, they are not recyclable with existing or upcoming technologies. Unless recycling improves to recover two different types of fibers, hybrid composites will not have a circular economy. There is growing activity in wind blade recycling, driven by regulations.

Automotive

The use of CFRP for vehicles will likely increase, especially with growing high-speed rail and other future mobility vehicles. With the industry diversifying, standardization of materials and design for specific parts will be key to ensuring that a common collection stream can be established for the postindustrial and post-consumer waste. There is growing activity for automotive recycling, driven by regulations.

Key Takeaway – A major differentiator for companies to commercialize and obtain significant market shares will be providing the end-of-life options and solutions upfront before adoption.

END-OF-LIFE PROCESSING

Strides made in recycled carbon fiber demonstrate new value propositions

There has been an increase in the number of CFRP recycling startups and technologies in the past decade, and they are starting to make fast progress. However, most recycling technologies are focused on postindustrial waste. CF recycling needs to also grow to post-consumer waste for complete value capture.

Most r-CF is used with thermoset polymers; however, there are some companies using r-CF with thermoplastics for 3D printing composite parts. The issue is that produced r-CF is usually in chopped form, which limits the applicability of the fibers. Startups are pushing to improve composite recycling processes and adoption, as regulations are unlikely to do so yet.

RECYCLED CARBON FIBERS

1 SOLVOLYSIS



vortega



ADESSO
Advanced Materials



AT



Extractive



connor technologies



bcircular

2 PYROLYSIS



ALPHA RECYCLAGE
COMPOSITES



EIG Carbon Fibre Ltd.
RECYCLED CARBON FIBRE



procotex



UNIVERSITY OF QUEENSLAND



CFK VALLEY STADE
RECYCLING™



VEOLIA

3 OTHER

Solid Carbon Products



carbon conversions



CIRCE
Canadian Engineering Hub for Carbon Fibre Recycling

OUTLOOK

Forming a CF circular economy can enable sustainability, adoption, and innovation in the industry

Sustainability is crucial for all industries; however, it usually has little economic value. The high value of CF recycling makes it attractive. Successfully recovering CF allows companies to regain some value, and r-CF is cheaper than virgin CF, which allows further cost savings. Moreover, recycling CF is a “simpler” and less resource- and energy-intensive process than forming virgin fibers, which is another cost-saving incentive. It eliminates the need for precursors and shortens the supply chain. As recycling avoids the energy consumption associated with the production of new materials, the recovery of materials with high embodied energy reduces the overall energy and cost while reducing the impact to the environment. The [Institute for Advanced Composites Manufacturing Innovation](#) estimates that recovering carbon fiber takes less than 15% of the energy used to make the original fiber. **This makes CF recycling attractive from both an economic and a sustainability standpoint.**

However, r-CF that is recovered is usually in chopped form, which is only usable for certain applications. Additionally, r-CF has inferior stiffness and tensile strength to virgin chopped CF, which also limits the application possibilities. While r-CF producers claim that the recycled fibers have very little loss of properties and can easily replace virgin fibers, composite part producers disagree with this claim. R-CF adoption is low, as there need to be more market studies and life cycle tests on how to incorporate and use it. **R-CF cannot be a “drop-in” replacement for virgin CF, but it can be used for new applications** in the automotive industry for nonstructural parts, for construction applications with steel and glass fibers, and in the growing 3D printing industry instead of chopped virgin fibers. **Ultimately, r-CF will expand the value of the market, not cannibalize existing applications for CFRPs, and push adoption overall.**

Standardization and circularity are interlinked, and their combined effect will grow the CFRP market

1

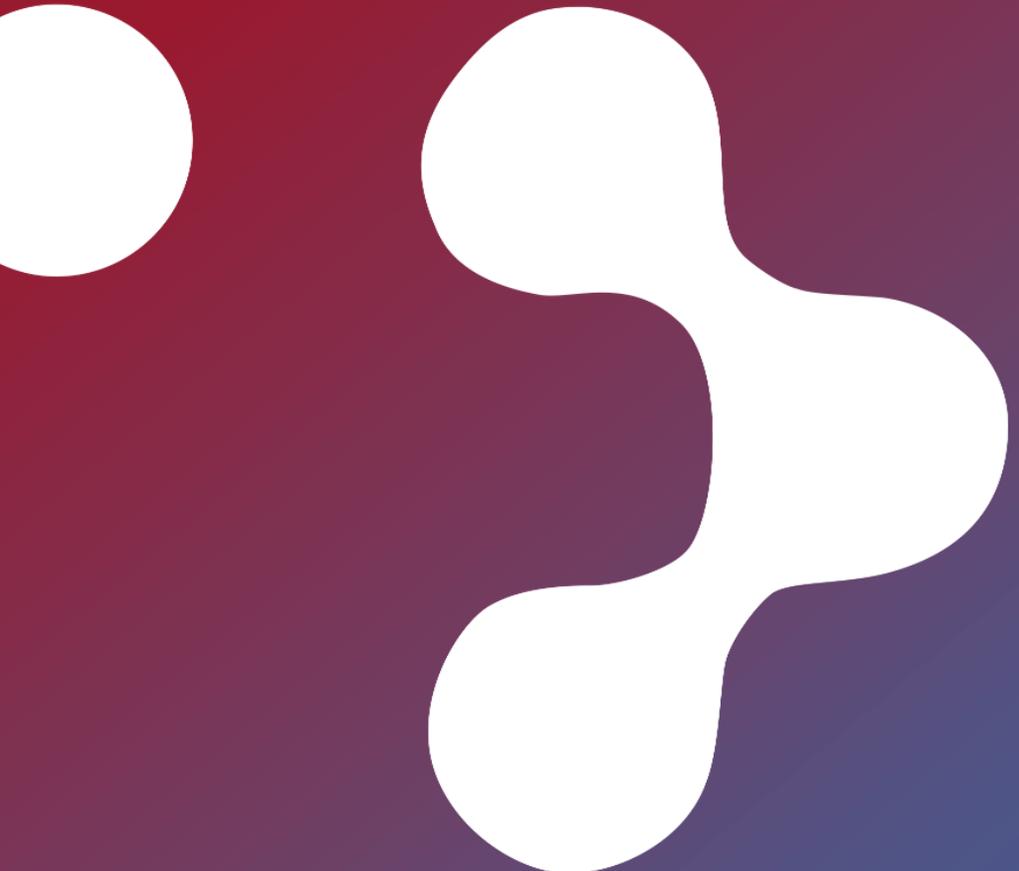
Standardization is the key to expanding CF recycling into a unified system. Standardization, while valuable in its own right, will also lead to the creation of more consistent r-CF, which will be much more straightforward to adopt. With more producers of standardized fibers and more suppliers of r-CF, the market for CFRP will expand.

2

Existing organizations will need to evolve to keep up. From major CF producers like Toray changing their pricing systems to companies like Teijin moving downstream into products, existing players will need to continue to respond to these trends. While core existing businesses in aerospace are unlikely to be displaced, there's a real risk of missing out on growth provided by new applications.

3

New kinds of products mean new value propositions and market dynamics. Groups have demonstrated meaningful value propositions across a broad spectrum of novel applications at today's prices, so there's clear momentum for adoption. However, it's increasingly clear that the relationships in these markets will be very different from the traditional CFRP markets.



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