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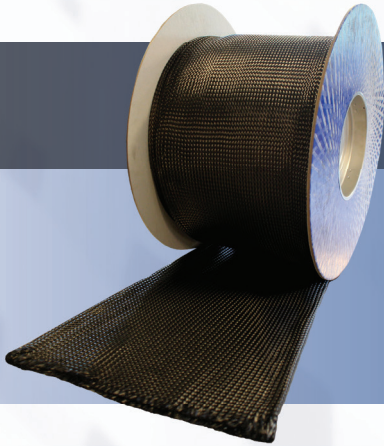
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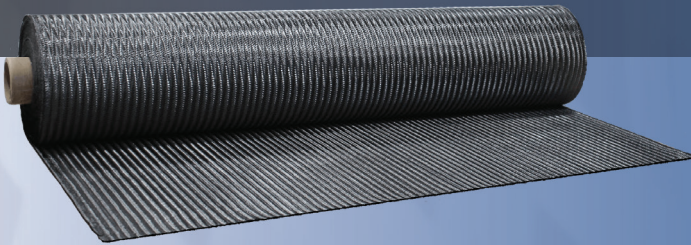
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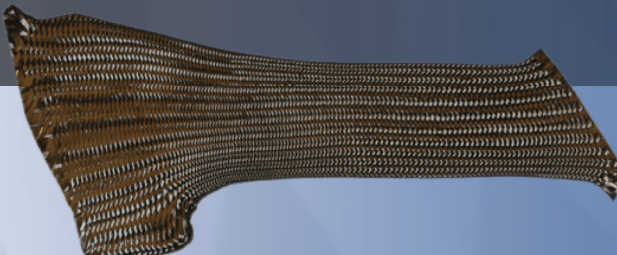
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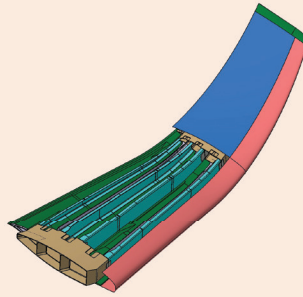
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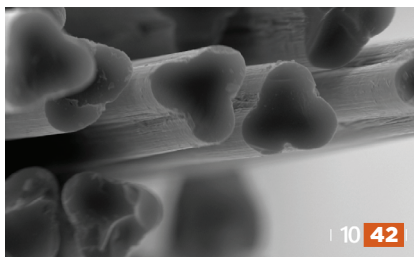
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Hexagon Composites continues to innovate future products in response to growing markets. Its Titan 510 Mobile Pipeline uses the company's largest Type 4 cylinder (shown here) in commercial production to date. Sized for 80,000-pound gross vehicle weight limits and optimized for high-volume gas transport, the Titan 510 Mobile Pipeline is helping to meet growing demand for energy from data centers. Hexagon Composites has also re-entered the aerospace market with multiple contracts and is assessing future product/performance needs as well as carbon fiber supply and optimized manufacturing as it projects continued growth in this and other segments. See p. 32. Source | Hexagon Composites

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Stay Ahead of the Trends Shaping Manufacturing

» *CompositesWorld* (CW) was founded on the conviction that composites manufacturing is too technically demanding, too application-specific and too consequential to be covered from a distance. That conviction hasn't changed. The deeply reported process articles, the features exploring material characterization, qualification and certification, the deep dives into supply chain and end market analyses — these exist because composites professionals need more than surface-level coverage to do their jobs well. That's what CW has tried to provide for more than three decades.

But depth and timeliness of information are different things, and composites professionals need both. The composites industry is one of the most technically complex and supply chain-entangled sectors in manufacturing. Fabricators are subjected to a wide range of variables: fiber and resin qualification timelines measured in years, not months; cure cycle parameters that determine mechanical performance and must be validated to customer specifications; autoclave scheduling that can make or break delivery windows; regulatory and certification requirements that govern what can be changed and how; and a supply chain of material suppliers, toolmakers, NDT providers and logistics partners, each operating within their own information environment and their own planning cycle.



On top of all that, the end markets that composites serve — aerospace, automotive, wind energy, marine, infrastructure — are themselves subject to forces that can shift quickly and substantially. Defense spending priorities evolve. Automotive OEMs change platform strategies. Wind blade demand tracks

policy environments that can reverse course. Each end market has its own rhythms, its own regulatory exposure, its own supply chain dynamics.

Most composites professionals are working with a picture that's assembled from fragments: a supplier conversation here, an industry report there. CW and parent company Gardner Business Media (GBM) are working to address the information gap and provide a more complete picture. This summer, we are launching Manufacturing Connected (MC), a daily intelligence platform built on the editorial foundation of GBM's brands — including CW, *Modern Machine Shop*, *Additive Manufacturing Media* and the Gardner Business Index — and structured around the decisions manufacturing leaders actually face.

The composites industry is unusual in the degree to which it sits at the intersection of so many forces simultaneously. A carbon fiber price movement is not just a procurement issue — it ripples through qualification decisions, competitive dynamics and capital spending plans. A defense budget adjustment is not just a revenue question — it shapes program timelines, tooling amortization assumptions and workforce requirements. A change in European end-of-life vehicle regulation is not just an environmental story — it touches how automotive OEMs and composites fabricators think about material systems, recycling investments and how to manage existing/new supply chains

CW editors have always understood that these connections exist. Therefore, MC is our effort to help you connect the dots in a timely manner. The goal is not to replicate the role of a deeply reported technical article, a carefully sourced supply chain analysis or a long-form investigation into why a process works or doesn't. That work is irreplaceable and remains the core of what CW does. What a daily intelligence platform like MC can do is sit alongside that work and fill the space between publication cycles — helping composites professionals see what's moving right now, why it matters and what to watch before the next issue lands in their inbox.

For more than 30 years, CW has covered the long arc of composites adoption — and that arc continues. But it's playing out now in an environment of remarkable volatility, where defense priorities can shift in a budget cycle, where EV strategies are being revised in real time and where supply chains are subject to uncertainty. MC is our answer to that need, a new resource to help you stay in front of the ever-changing trends that influence manufacturing.

To learn more or to subscribe visit mfgconnected.com. CW

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 **Chem
Trend**

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Cambium's \$100 Million Play: Fundraising Engineering Meets Composites Scale

By Yannick Willemin / President, Catalysium

» In composites, we spend a lot of time talking about technical integration: how fibers, resins, formats, equipment and processing need to align to create a viable product. We spend less time talking about financial integration. And yet, sometimes the most interesting innovation is not only in the chemistry or on the manufacturing floor, but in the way a company assembles capital, assets and people around a market need.

That is why Cambium caught my attention.

The El Segundo, California-based advanced materials company announced a \$100 million Series B in January 2026, led by 8VC. Just weeks earlier, Cambium had announced the acquisition of U.K.-based SHD Group, the established advanced composites manufacturer now operating as “SHD, a Cambium company.”

Taken separately, each announcement was noteworthy. Together, they suggest something more strategic.

Cambium has positioned itself as an advanced materials innovator working on difficult problems in defense, aerospace and other high-performance sectors. Publicly, the company emphasizes AI-enabled materials discovery and the creation of new monomers and polymers, not just reformulations of existing chemistries. SHD, by contrast, brings an established prepreg platform, a global footprint and decades of accumulated know-how in advanced composite materials manufacturing. Cambium says

the acquisition gives the combined company an innovation- and aerospace-qualified manufacturing footprint spanning the U.S., the U.K. and Slovenia.

This is where the story becomes more interesting than a classic startup funding round. At JEC World, Brett Schneider, now president of SHD and Cambium Composites, described the logic in unusually direct terms: “How do you scale a materials company when in this industry it’s fairly asset-heavy at times?” His answer was equally direct: “Putting the two companies together under Cambium’s new manufacturing vertical for composites just made a ton of sense and accelerates commercialization of new chemistries.”

That line deserves attention because it reframes the role of fundraising. In many startup stories, capital is presented as validation. Here, it looks more like industrial design.

Schneider is a credible guide to that logic. He brings three decades of experience in advanced materials, automation and industrial leadership. Before joining Cambium’s board in 2025, he held leadership roles at Hexcel, served as chairman and CEO at Carbon Conversions and worked as an operating partner at Arsenal Capital. In other words, he not only understands how composites businesses are run. He understands how industrial platforms are built.

That may explain why the Cambium-SHD construct feels unusual, but also smart.

In our discussion, Schneider described how the relationship began through toll manufacturing and then evolved as the teams recognized an unusually strong cultural and strategic fit. “It became obvious that we should just put the two companies together,” he said.

“Culture” can sound soft in dealmaking language, but in composites it matters. Materials businesses are not software businesses. They depend on tacit know-how, process discipline, customer trust and the ability to move from development to production without compromising quality. That is also why the transaction appears to be about more than adding manufacturing capacity.

In our interview, Schneider pointed to another layer of value that is easy to overlook: data. He described the acquisition as giving Cambium access to thousands of validated recipes that can now help feed and train its algorithms. As he put it, “At the end of the day, I have a

■ Cambium is backed by more than 20 different funding sources. Sources | Getty Images (top) and Yannick Willemin (bottom)





■ Brett Schneider (left) discusses how to scale an AI materials company during an interview on The Composites Catalyst. Source | Yannick Willemin

Scaling an AI materials company



Readers interested in hearing Brett Schneider expand on Cambium, SHD and the broader scaling strategy can watch the full interview recorded at JEC World on @Composites Catalyst, the newly launched YouTube channel by Catalysium.

database now that is almost second to none that I can feed into our AI machine and let it actually do things quicker.”

This is where I think the story becomes bigger than Cambium alone.

We often hear about financial engineering as something abstract or detached from industrial value creation. What Cambium appears to be doing is different, better described as fundraising engineering: using capital not simply to extend the runway, but to assemble a faster commercialization system enabling targeted adoption of new materials.

At JEC World, Schneider said the company was already moving products out of the R&D environment and into applications only a few months after bringing the businesses together. He also described how SHD’s installed capabilities were being expanded quickly, including the commissioning of a wide-format line to broaden product output. Publicly, SHD announced that expansion in February 2026 as part of its long-term growth strategy under the combined organization.

Of course, this kind of strategy is not risk-free. M&A can destroy value as easily as it creates it. Integration is never automatic,

especially when a young, venture-backed innovator combines with an established manufacturing culture. But when it works, it offers a compelling model for advanced materials startups operating in capital-intensive sectors.

Rather than waiting years to build every capability internally, they may be able to combine invention with acquisition, provided they respect the operational culture and customer expectations that made the target valuable in the first place.

There is also a quiet but important detail behind the transaction. Publicly, Future Materials Group (FMG, Cambridge, U.K.) said it acted as SHD Composites’ exclusive sell-side M&A advisor on the sale to Cambium. That is worth noting because the deal did not look like a routine handover. It was a structured combination of timing, capability and capital, and it required the kind of market understanding that specialist advisors can bring to advanced materials transactions.

Cambium’s story is still being written. But it already offers a useful signal for the composites market. In this industry, capital may be evolving from a source of financing into a tool of industrial assembly. And that is a development worth watching. **CW**



ABOUT THE AUTHOR

Yannick Willemin has an engineering degree in materials and mechanics from École Polytechnique de l’Université d’Orléans in France. Over the course of 13 years, he has held multiple positions at SGL Carbon, gaining deep expertise in the composites industry. At the same time, he earned two EMBA degrees with a focus on finance and entrepreneurship. Afterward, he joined ETH Zurich spinoff 9T Labs as head of business development. Since January 2025, Willemin has been working independently, positioning himself at the intersection of startups, industrial players and investors to drive innovation across the composites landscape with the founding of Catalysium. yannick@catalysium.ch

CAMX SHOW PREVIEW



WHAT:

Composites and Advanced Materials Expo (CAMX) 2026

WHO:

American Composites Manufacturers Assn. (ACMA, Arlington, Va., U.S.); Society for the Advancement of Material and Process Engineering (SAMPE, Diamond Bar, Calif., U.S.)

WHEN:

September 21-24, 2026

WHERE:

Georgia World Congress Center, Atlanta, GA

By Hannah Mason, Technical Editor

The Composites and Advanced Materials Expo (CAMX) returns to the Georgia World Congress Center (GWCC) in Atlanta Sept. 21-24, 2026. Co-hosted by the American Composites Manufacturers Association (ACMA, Arlington, Va., U.S.) and the Society for the Advancement of Material and Process Engineering (SAMPE, Diamond Bar, Calif., U.S.), this year's trade show is expected to attract 7,000-plus attendees with the opportunity to visit 500-plus exhibits and learn from more than 100 technical and education sessions.

Still need to register? Start here

Register or update your registration at thecamx.org/registration. New in 2026, all CAMX registrations include featured session access, three streamlined pass options — Expo Hall, Full Conference and Student — and a variety of à la carte tutorials are available for a customized learning experience.

Once you have your badge in hand, visit thecamx.org/travel for tips on booking travel and hotels in Atlanta.

Once the logistics are set, it's time to make your trade show game plan. What can you expect at the rest of the show?

Don't skip the General Session

The morning of Tuesday, Sept. 22 kicks off with the General Session, sponsored by Composites One, in the venue's Georgia Ballroom. This session serves to welcome attendees to this year's CAMX edition, and includes the presentation of the prestigious CAMX Awards for Combined Strength and Unsurpassed Innovation, and a keynote from Kevin Gaskell, former group CEO of BMW GB, Porsche GB, Lamborghini GB and Fairline Yachts.





Grab physical copies of the Show Daily each day of CAMX on the show floor.

Browse conference sessions

In addition to featured sessions on the show floor, there are also a variety of technical paper presentations and in-depth education sessions providing more in-depth knowledge sharing opportunities on a variety of topics. Check thecamx.org/conference-program for the most updated program information.

Take advantage of networking opportunities

One of the best reasons to attend a trade show is to connect in-person with colleagues in your field. If you're a first-time attendee, check out the First Time Attendee Orientation Breakfast before the General Session on Tuesday to

Gaskell brings his experience driving growth and performance at these companies, as well as his current roles as an investor and entrepreneur across automotive, data, technology and manufacturing sectors. He's also a Top 40 U.K. Leader, a global brand advisor and conference speaker.

In his keynote, Gaskell will share real-world strategies for driving transformation, how to build and inspire high-performance teams, lessons learned from turning around global brands and the mindset needed to tackle the biggest challenges.

Experience the show floor

There are more than 500 exhibitors showcasing the latest materials and process technology. As you devise your game plan for the event, make sure to schedule in some of the other must-sees:

- New for CAMX 2026, **Featured Sessions** are located on the floor and are accessible with all attendee passes. These will take place at the new CAMX Innovation Stage and Awards Pavilion. These sessions provide opportunities to learn about and discuss top industry topics like bridging the gap between academic research and industry, the advanced air mobility (AAM) supply chain, launching products at speed, composites in geothermal and oil/gas, industrialization of new raw materials, barriers and opportunities for composites in architecture and building materials, and automation.
- **Dedicated areas** show off all of the CAMX Award winners and finalists, and the Awards for Composites Excellence (ACE) winners and finalists.
- The Composites One Demo Zone provides a lineup of **live demonstrations** to teach both the basics of composites manufacturing and some of the latest technologies.
- The Hive provides **space for networking** and taking a respite from the show floor.

meet other new faces around CAMX. Additional structured networking activities throughout the event include Tuesday evening's Welcome Reception and Wednesday afternoon's Young Professionals Meet-Up. There will also be plenty of chances to meet new industry contacts on the show floor!

Keep up with the latest

Finally, you'll want the latest updates as they happen. There are a variety of ways to stay up-to-date on what's happening before and during the show:

- Find exhibitor previews of technology you'll see at the show at compositesworld.com/zc/camx-forecast.
- Check out CW editors' live reporting from the show floor in the physical Show Daily newsletters on-site and digital versions at compositesworld.com.
- Sign up for CAMX Alert emails to stay updated with news from the show.
- Download the CAMX App for up-to-date schedule information and an interactive map.
- Follow on social media: CAMX on LinkedIn and Facebook; *CompositesWorld* on LinkedIn, Facebook and Instagram.

The CW team looks forward to seeing you there! **CW**



ABOUT THE AUTHOR

Technical editor Hannah Mason has been writing and editing about composites for *CompositesWorld* since 2018. She has a Master's degree in professional writing from the University of Cincinnati. hmason@gardner.media

CW Talks



THE COMPOSITES PODCAST

EPISODE 57

Francesco De Stefano, Caracol

» In this installment of CW Talks, *CompositesWorld* speaks with Francesco De Stefano, CEO and co-founder of Caracol (Milan, Italy), about the company's proprietary robotic large-format additive manufacturing (LFAM) platform for composites. What began as a research effort to combine the flexibility of additive manufacturing (AM) with the scale of robotics has now evolved into a distributed production model serving aerospace, maritime, transportation and defense markets. De Stefano discusses how Caracol moved from service bureau to production platform provider, why pellet-based composites printing changes the economics of large parts, and how AI and machine learning are being embedded into the manufacturing process itself.

CompositesWorld (CW): Can you give us a bit of background about Caracol — your mission and the markets you serve?



■ Francesco De Stefano, CEO and co-founder of Caracol. Source | Caracol

Francesco De Stefano (FDS): Caracol operates in the world of large-format advanced manufacturing. Our focus is developing and delivering solutions for producing large-format parts — we're talking half a meter up to several meters — for highly regulated industries ranging from aerospace and defense to transportation, automotive and maritime industries. We do that with a proprietary robotic LFAM platform for composite materials, our Vipra AM system, which we've extended to metals as well.

CW: You transitioned from a service bureau model to qualifying production parts for demanding industries. How did that journey shape the way you work with customers today?

(FDS): It all started back in 2015 when two of our co-founders, Giovanni and Paolo, recognized that AM had tremendous potential but was limited in scale. They had the intuition to combine it with robotics — creating a platform that could leverage the advantages of AM at a scale that didn't previously exist for large parts.

We spent three years in R&D, and by late 2017 and early 2018, we found ourselves with a technology that the market hadn't yet seen. Rather than immediately selling the platform, we decided the best way to validate a new technology was to use it ourselves on real projects. That service bureau model turned out to be one of our biggest long-term advantages — it forced us to learn the technology from an end-user perspective, and it allowed us to unlock application qualifications with OEMs and Tier 1 and Tier 2 suppliers in key industries.

After about 5 years of operating that way, we realized the market was ready and the technology was mature enough to scale. And the way to scale it — especially internationally — wasn't by growing our own factories, but by creating a distributed production model: getting manufacturing as close as possible to where the parts are used, reducing logistics and helping customers internalize the technology. We still run a fully EN 9100-certified production center in Italy for aerospace qualifications, but when it's time to scale production, we help customers bring the capability in-house. That's the business model shift we made at the end of 2022 when we launched the Vipra platform.

CW: What sets your large-format composites 3D printing platform apart from other AM systems?

FDS: It shares some advantages with AM generally — digital supply chains, inventory digitization, the ability to eliminate molds in certain cases. But what really distinguishes it is the combination of scale, flexibility and economics.

When you're talking about very large parts, logistics becomes a major component of cost and carbon emissions. Eliminating or reducing that has a much larger impact than it does with smaller additive parts. The robot itself is also key: Compared to a standard gantry-based system, it's less expensive, more flexible and



■ Racing car roof produced using robotic LFAM. Source | CW

operates on six axes — enabling complex geometries without the need for support structures. And by working with pellets rather than filament, we're able to reduce material costs to roughly one-fifth or one-tenth of what filament of the same material would cost. That, combined with production rates measured in kilograms per hour, drives the business case in a way that simply isn't possible with smaller-scale systems.

CW: Composites 3D printing is often associated with tooling. Can you talk about the shift toward end-use parts?

FDS: Tooling was absolutely the starting point. Our first aerospace qualifications were jigs — assembly jigs for aircraft panels that today are milled from aluminum or metal profiles, assembled by hand, with long lead times and expensive custom materials. With our process, you can produce the same jig as a single monolithic part and then machine it to tolerance, wasting less than 5% of the material compared to 70% or more in some CNC processes.

From there, we moved into lamination molds — tools for fiber-glass lamination that are subject to heat and pressure — with similar advantages in lead time and material waste, but even greater impact because aerospace-grade mold materials are often very expensive.

Then, about 3.5 years ago, we realized through our service bureau work that the real opportunity in certain composite industries, particularly maritime, wasn't in making the molds at all. In yacht building, molds are often made from foam or wood — cheap by aerospace standards. The real problem was the labor-intensive process of assembling molds and manually laminating glass fiber. If we could go straight to the finished part, we could eliminate that entire bottleneck.

We've since qualified several end-use part types that come straight off the machine and are finished exactly as they would be in traditional glass fiber processes — no mold required. A well-known public example is the 4-meter lateral air grille we produced for the Ferretti Group's Pershing line. It's a complex geometry that would have been extremely difficult to mold conventionally, and it's now in recurring production on multiple vessels at sea. We handled the full process, from design engineering through final qualification, including UV exposure and salt spray aging tests to validate performance against glass fiber equivalents. »

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The same approach extends to custom vehicles, automotive interior panels, van components and certain spare parts applications. We're also seeing strong interest in unmanned surface vessels for maritime monitoring and critical infrastructure, where the entire hull becomes a candidate for this manufacturing approach.

CW: How do you approach application development, particularly in highly regulated industries?

FDS: We have a framework we've refined over 6 years. When evaluating a new application, we look at five or six key parameters: production volumes, mechanical property requirements, thermal performance, dimensional tolerances, geometry complexity and — for composite parts specifically — process compatibility.

That qualification step is critical. When this technology fits the right application, the cost savings can be 30%, 50%, even 70%. When it doesn't fit, the cost can be 3X higher. So, a big part of our job is helping customers identify their best candidates first.

From there, in regulated industries, we work side by side with OEMs through the full certification process. We've found that a lot of AM adoption stalls because companies focus so much on the machine that they miss all the downstream steps — process certification, procurement specification updates, technology transfer.

We've been doing those steps from the beginning, and that's why we built an integrated ecosystem. Customers aren't just internalizing a machine. They're changing their supply chain, and they need a partner who can guide that entire transition.

CW: Can you talk about the dual-use nature of your work — where civil and defense applications converge?

FDS: It's actually quite natural for us. Many of our customers in northern Italy are in the supply chains of the automotive industry. As the European automotive sector has faced headwinds over the past couple of years, many of those companies have been diversifying.

The underlying technology — producing complex composite geometries on demand for land vehicles or maritime platforms — is substantially the same regardless of the end use. A chassis component or structural cover for a transportation platform can serve a mobile dental clinic or a military troop carrier. The manufacturing process is identical; the requirements differ in terms of specifications and certifications. So when we're developing parts for transportation, those same components and processes are natural candidates for defense applications in the same domain.

CW: Let's talk about automation and the role of AI. Manpower is a real bottleneck in composites manufacturing. How are you addressing that?

FDS: The bottleneck is very real. Yacht builders we've worked with have been experiencing double-digit growth, but that growth is capped by manpower, because every step of their process requires skilled operators who are increasingly hard to find and retain.

If you eliminate the mold step and deploy robotic systems to produce the part directly, you can run five machines with one or two operators, potentially lights-out overnight. That's a fundamental shift. And we've worked hard on the software side to make the machines accessible — operators don't need to know robotic programming languages to run a Caracol system.

But there's a further layer of automation we're building now through AI. We have years of production data, and we're feeding that into machine learning models to simplify the path from design to print. The slicing and toolpath programming process becomes faster and less prone to operator error, with presets driven by the application database.

Beyond programming, we're automating operational tasks like part removal, print setup and calibration. And perhaps most importantly, we're embedding real-time process monitoring: sensors on the machine read what's happening during deposition, compare it to the intended tool path and make automatic adjustments if the system is deviating. That translates directly to higher productivity, less waste, more machine uptime and ultimately a stronger business case for our customers. **CW**



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TRENDS

GRAPHENE

NIOSH Study Measures Graphene Exposures in U.S., Sets Benchmark

Workers who handle graphene as a dry powder face airborne exposure far above a proposed safety benchmark, while handling it in liquid or solid form significantly reduces exposure, according to a study presented May 15, 2026, in a webinar hosted by the Advanced Carbons Council. The National Institute for Occupational Safety and Health (NIOSH) reported the first set of U.S. workplace exposure measurements for the graphene family of nanomaterials.

Dr. Matthew Dahm, an industrial hygienist at NIOSH's Cincinnati, Ohio office, sampled 44 workers at 11 companies and analyzed 155 elemental carbon (EC) samples. Respirable EC ranged from below 0.01 to 1,825 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$); inhalable EC ranged from 0.01 to 6,327 $\mu\text{g}/\text{m}^3$.

■ Published occupational exposure limits (OELs) for bulk carbonaceous materials and carbon nanotubes (CNTs) alongside preliminary values for graphene. Source | M. Dahm, NIOSH

Carbonaceous Material	Size Fraction	OSHA PEL	MSHA PEL	NIOSH REL	ACGIH TLV	Preliminary OEL
US OELs						
Graphite (synthetic)	Total/Inhalable	15,000			10,000	
Graphite (synthetic)	Respirable	5,000			2,000	
Graphite (natural)	Respirable	2,500		2,500		
Carbon Black	Total	3,500		3,500		
Coal Dust (bituminous or lignite)	Respirable		1,500	900	900	
Coal Dust (anthracite)	Respirable		1,500	1	400	
CNTs/CNFs	Respirable					
Independent Risk Assessments for Graphene						
GFNs – OEB	None specified					<10
(Niang et al. 2025)						
GNP	None specified					212
(Spinazzè et al. 2019)						
GO	None specified					18
(Lee et al. 2019)						

A benchmark where none existed

No authoritative occupational exposure limits (OELs) currently exist for graphene, a gap Dahm called common: roughly 84,000 chemicals are in U.S. commerce against only a few thousand established OELs. NIOSH applied its Occupational Exposure Banding process, sorting materials into one of five potency bands (A through E) using available toxicological data.

A literature review returned about 7,470 records, of which 24 in vivo studies met the criteria for banding. Across nine toxicity outcomes, graphene was assigned to Band E, the most potent classification, driven by target organ toxicity, genotoxicity and respiratory sensitization — corresponding to a preliminary OEL of less than 10 $\mu\text{g}/\text{m}^3$. For comparison, bulk graphite OELs range from roughly 2,000 to 15,000 $\mu\text{g}/\text{m}^3$, and the only authoritative OEL for a carbonaceous nanomaterial, carbon nanotubes (CNTs), is set at 1 $\mu\text{g}/\text{m}^3$. Two independent risk assessments have proposed preliminary graphene figures of 212 $\mu\text{g}/\text{m}^3$ for graphene nanoplatelets and 18 $\mu\text{g}/\text{m}^3$ for graphene oxide.

Measuring and mapping exposure

NIOSH measured EC using method NMAM 5040, collecting paired respirable (below 4 μm) and inhalable (below 100 μm) samples per worker, alongside electron microscopy to confirm graphene content, subtracting background readings taken in clean areas away from production. The 11 companies sampled included seven primary manufacturers and



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secondary manufacturers spanning electronics, composite additives and distribution, handling graphene nanoplatelets, graphene oxide, few-layer graphene and other forms.

Exposure distribution was log-normal. For respirable EC, the geometric mean was $2.01 \mu\text{g}/\text{m}^3$ and the arithmetic mean $82.27 \mu\text{g}/\text{m}^3$; for inhalable EC, the geometric mean was $12.63 \mu\text{g}/\text{m}^3$ and the arithmetic mean $250.21 \mu\text{g}/\text{m}^3$. Measured against the $10 \mu\text{g}/\text{m}^3$ band, 38% of respirable samples and 53% of inhalable samples exceeded it.

Roughly 59% of workers handled dry powder, 42% liquid and 31% solid forms at some point; engineering controls were limited, and 45% used respiratory protection. A regression model found that handling more than 100 kilograms or dry powder increased exposure, while solid forms decreased it; longer direct handling time also increased worker exposure.

Comparable risk, opposite drivers

Dahm compared the results to NIOSH's earlier CNT work, where the highest respirable exposure measured was about $80 \mu\text{g}/\text{m}^3$ and inhalable about $709 \mu\text{g}/\text{m}^3$ — both well below the graphene maxima of roughly 1,800 and 6,300 $\mu\text{g}/\text{m}^3$. Framed through risk = hazard $\times$ exposure, graphene's hazard appears lower than CNTs, "but the exposures NIOSH measured were higher... it might actually be fairly similar."

Controls and the path forward

Dahm said exposure data is the starting point for establishing an OEL, since it informs the animal toxicity testing risk assessors need. Background carbon levels are typically under $1 \mu\text{g}/\text{m}^3$, far below workplace readings, and dermal exposure appears limited compared to inhalation.

Advanced Carbons Council executive director Terrance Barkan distinguished dry powder graphene from graphene compounded into a paste or polymer pellet, advocating masterbatch formulations to cut exposure. Dahm agreed that solid or liquid forms reduce exposure potential for graphene and CNTs alike. On end of life, Barkan said graphene cannot practically be liberated from a cured composite by sanding, grinding or cutting; Dahm noted low graphene loading in most products makes recycling exposure unlikely to be a concern except at very large volumes.

Both speakers agreed nanocarbons can be used safely with the right procedures. For composites fabricators, the guidance is to avoid handling nanocarbons as dry powder and instead work with compounders that can supply graphene already embedded in a paste, dispersion or polymer pellet.

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SPACE

Rocket Lab to Acquire Iridium, Form Vertically Integrated U.S. Space Entity

Rocket Lab Corp. (Long Beach, Calif., U.S.) and Iridium Communications Inc. (McLean, Va., U.S.) a provider of global voice, data and positioning, navigation and timing (PNT) satellite services, have entered into a definitive agreement under which Rocket Lab will acquire Iridium. This deal will include all outstanding shares of Iridium common stock for \$54 per share in a cash and stock transaction. This represents an enterprise value for Iridium of approximately \$8 billion.

Sources say that this acquisition will be “one of the most transformative deals in the space industry,” creating a competitive, vertically integrated U.S. space company that designs, builds, launches and operates its own constellations. It merges Rocket Lab’s launch capabilities, satellite

manufacturing and composites expertise with Iridium’s global satellite communications network, spectrum and 500-plus-strong partner ecosystem.

The transaction will give Rocket Lab an immediate foothold in space-based applications, including proprietary and standards-based satellite Internet of Things (IoT) and direct-to-device (D2D), PNT and critical safety-of-life services. Rather than simply continuing the Iridium network, Rocket Lab will build upon it to scale into untapped markets and pioneer new space-based services to the benefit of global customers.

“By marrying Iridium’s deep heritage, trusted infrastructure and highly sought-after spectrum with Rocket Lab’s extensive and proven launch and manufacturing capabilities, we have the capability to unlock entirely new markets,” says Sir Peter Beck, founder and CEO of Rocket Lab. The entity is anticipated to deliver next-generation satellite communications, resilient PNT and emerging defense and commercial space services.

Matt Desch, CEO of Iridium, notes that as the worlds of space and terrestrial communications continue to converge, “success will come from those who can bring new innovations to space quickly and sustain them over time as efficiently as possible.”

The transaction is expected to be completed in mid-2027, subject to the satisfaction of customary closing conditions, including approval of Iridium stockholders and required regulatory approvals.



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DEFENSE

Bell Completes First Two Wing Structures for MV-75 Cheyenne

Bell Textron Inc. (Fort Worth, Texas, U.S.) has successfully completed the assembly of two composite wing structures for the MV-75 *Cheyenne* (previously the V-280 *Valor*). Bell will integrate these wings into the first two MV-75 test aircraft, advancing the program's build process.

The tiltrotor wing is a key piece of structure for the MV-75. It provides the structural backbone of the aircraft with robust strength, optimized stiffness and enhanced survivability. The wings are a core competency for Bell; all key components are made within its Advanced Composite Center and other facilities, including the composite wing skins and spars, the tailored aluminum substructure and assembly.

"After decades of building V-22 wings, we've learned new ways to do things better, faster and smarter by implementing these lessons into the design upfront," says Culley Shafer, director of operations, Amarillo, Bell. "The team is constantly evolving, making adjustments, refining sequencing and implementing engineering changes to keep raising the bar on quality, safety and efficiency."

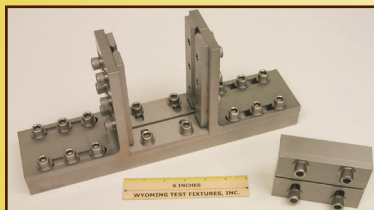
The first wing, completed in February 2026, was fabricated with 90% fewer labor hours compared to the initial V-22 wing build. Building on this success, the second wing was produced with an additional 40% reduction, highlighting a focus on affordability and production readiness.



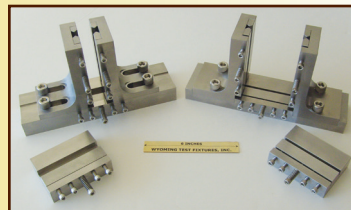
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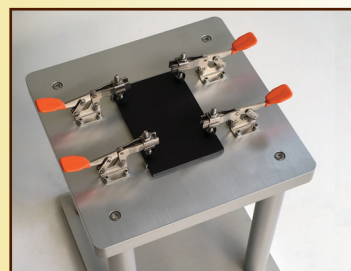
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AUTOMOTIVE/MASS TRANSIT

PulPro-SMC Project Achieves Weld-Free Composite Rail Vehicle Joints in Single Pressing Step

A 3-year German research consortium has concluded its PulPro-SMC project with a working demonstrator that achieves material-bonded connections between pultrusion profiles and SMC nodes in a single pressing step — eliminating the separate joining technology typically required when combining composite structures.

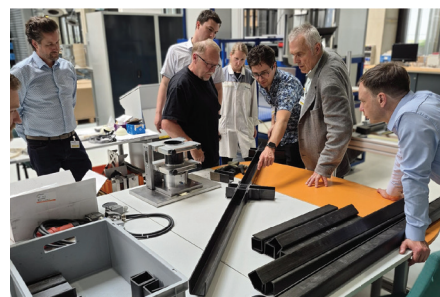
The project's final meeting, held in mid-June 2026, brought together all five consortium partners for presentations of individual results, live pressing tests and the unveiling of a demonstrator: A sidewall segment intended for rail vehicle applications. According to project lead HÖRMANN Vehicle Engineering GmbH (Chemnitz, Germany), the bonded connection reduces weight by 20% compared to conventional steel construction, and mechanical properties measured during testing exceeded what finite element method (FEM) calculations had predicted.

The PulPro-SMC project ran from October 2023 through June 2026, funded within the KoPa4Mobility program by Germany's Federal Ministry for Economic Affairs and

Energy and managed by TÜV Rheinland Forschungs- und Innovationsmanagement. Its central objective was to produce a material-locking frame structure from pultruded fiber composite profiles as an alternative to the conventional method of welding steel profiles — a combination the project description characterizes as requiring a balance of "lightweight construction, crash safety and cost-effectiveness." The project also focused on the use of recycled carbon fibers (rCF) in the SMC component.

The joining challenge addressed by PulPro-SMC is a longstanding limitation in composite construction. Adhesive bonding holds but introduces variability, and mechanical fasteners such as screws weaken fiber orientation at the joint. The PulPro-SMC approach fuses pultrusion profiles and SMC nodes under pressure and temperature in a single press cycle, leaving no discrete joining hardware and no associated stress concentration.

One technical challenge that required sustained effort across the consortium was fire protection. To achieve HL2 R1 fire classification — a standard applicable to rail vehicle interiors — the project incorporated aluminum hydroxide (ATH) as a flame retardant.



According to HVE, ATH complicated processing in both pultrusion and SMC pressing operations, and resolving those difficulties required coordinated work across all partners.

Next steps include interlinking and automating the process chains to reduce cost, prototype testing within a vehicle and evaluation of the technology's transfer potential to other applications where lightweight structural performance is required, such as road vehicles and bus body structures.

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SPORTS/RECREATION

Acciona, Bolero Surf Create Surfboard Fins From Recycled Wind Blades

Acciona Energia (Madrid, Spain) has partnered with Bolero Surf (Sydney, Australia) to produce what the companies say are the first commercially available surfboard fins made from 100% recycled wind turbine blade fiberglass. The fins were launched at the 2026 NRMA Insurance Australian Boardriders Battle on the Gold Coast, where professional surfer Darcy Crump used them in competition.



The project is part of Acciona's Turbine Made initiative, which explores ways to repurpose retired wind turbine blades into new materials and products. This is particularly true as Australia faces a growing challenge over the next 5-10 years with a wave of decommissioned turbine blades that will require end-of-life solutions.

The fins in question were designed by Banjo Hunt, founder of Bolero Surf, who spent years evaluating recycled fiberglass feedstocks — including caravan panels and boat hulls — before identifying turbine blade material as a viable option. Hunt says most alternatives fell short due to loose weaves and excess resin that compromised the flex and strength required for high-performance fins. The fiberglass found inside turbine blades, by contrast, offered the consistency and structural integrity the application demanded.

The material's reuse also reduces reliance on virgin resources and eliminates one of the more expensive and labor-intensive steps in conventional fin manufacturing — an advantage Hunt says is helping Bolero Surf consolidate its production in Australia.

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MARINE

CWS Completes Full-Scale Airfin350 Rigid Wing Prototype Test Campaign

CWS – Computed Wing Sail (Montoir-de-Bretagne, France), developer of a patented automated rigid wing sail system for maritime propulsion, has moved its full-scale Airfin350 prototype from assembly to active testing at Nantes-Saint Nazaire Port (France). The 40-meter Airfin350 prototype recently completed its first on-site test campaign, exposing

the structure to real wind conditions on port grounds selected for favorable wind exposure. The wing features an asymmetrical aerodynamic profile — modeled on aircraft wing geometry — combined with a patented folding and inversion system that allows it to tack efficiently while reducing air draft when needed.

The Airfin350's CFRP construction has been previously detailed in CW coverage of SMM Composites (Lanester, France), which produced 54 CFRP omega-section reinforcements for three wing sail units using a six-cavity resin infusion mold and large-scale 3D printed machining fixtures. CWS states the system is designed to deliver fuel savings and CO₂ emissions reductions compatible with IMO EEDI, EEXI and CII regulations, as well as European ETS and FuelEU requirements.

With prototype testing now complete, CWS reports its first commercial project is underway in partnership with Windcoop (Lorient, France), in which its vessel, the *Miaraka*, is slated to be equipped with three Airfin350 automated rigid wings for service between Marseille and Madagascar.



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AUTOMOTIVE

BMW X5 Enters Final Test Phase, Prepares for 2026-2028 Series Rollout

BMW Group (Munich, Germany) has announced new strides in the BMW X5 sports activity vehicle (SAV) lineup. The company's new BMW X5 (gas and hybrid) has entered the finish line in its development program and is now completing final calibration drives around its production base at BMW Group Plant Spartanburg in the U.S. The X5 will be the first BMW production model to be introduced onto the market with a choice of five different drive system technologies.

The first fully electric BMW *iX5* (EV) will be making its debut, and this will be followed in 2028 by the arrival of the first hydrogen-powered BMW to go into series production — the BMW *iX5 Hydrogen*. Also available will be petrol

and diesel variants with 48-volt mild hybrid technology and plugin hybrid models.

Fully electric BMW *iX5*. This battery-electric vehicle is based on sixth-generation BMW eDrive technology which features a high-voltage battery concept with cylindrical cells and 800-volt technology. With its usable energy content of 144 kilowatt-hours (kWh) in the U.S. and 141 kWh in the EU (net), the BMW *iX5* 60 xDrive boasts the largest high-voltage battery to be fitted in an all-electric BMW model to date, BMW reports. Propulsive power is provided by one electric motor at the front axle and another at the rear, working in tandem with BMW xDrive electric all-wheel drive.

BMW *iX5 Hydrogen*. This hydrogen-powered BMW production model has a powertrain comprising a fuel cell system, the BMW Hydrogen Flat Storage system and a high-voltage battery. The third-generation fuel cell system forms the basis for a compact design, high power and efficiency. The flat tank system consists of seven high-pressure Type 4 CFRP pressure vessels connected with one another in parallel. These are integrated into a robust metal frame. This layout makes optimal efficient use of system space; no room is lost inside the cabin.

All versions feature an in-house-developed Dynamic Performance Control driving stack. The wheels — larger rims with diameters of up to 23 inches can now be specified — and the standard mixed-size tires further enhance comfort, stability and dynamism. Additional features include a next-gen drive assistance system.



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AAM

Honda Hits Milestone With Successful First EVTOL Aircraft Flight

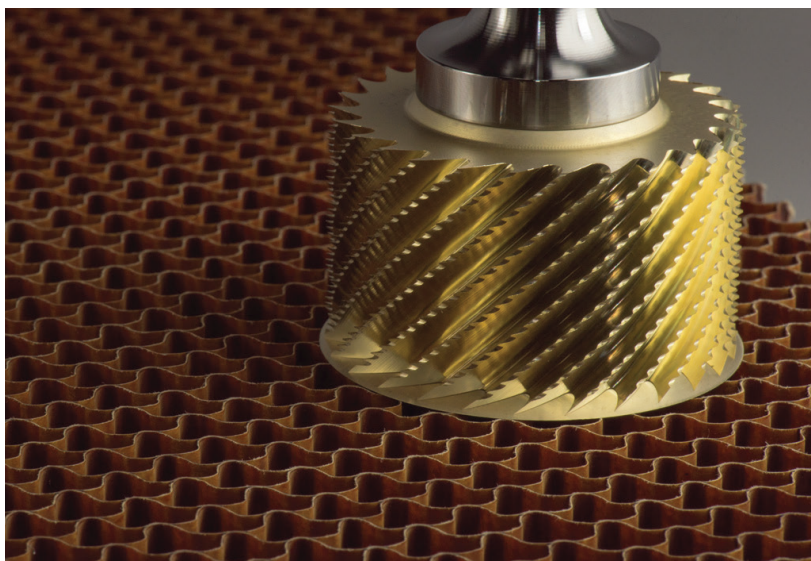
At the beginning of April, a successful flight test was conducted in San Luis Obispo County, California, for Honda's (Tokyo, Japan) full-scale eVTOL technology demonstrator, called *F1*. The first flight lasted about 90 seconds.

The automaker began R&D efforts in 2020, with plans to enter the eVTOL market announced in 2021 coinciding with the hybrid aircraft concept launch. This most recent flight is the culmination of more than 400 flight tests conducted using sub-scale models, Honda reports.

The full-scale demonstrator, weighing $\approx 7,000$ pounds, is equipped with eight rotors for vertical takeoff and landing and two rotors for propulsion. It features a gas turbine hybrid power unit and makes use of Honda's "expertise in lightweight structures and production technologies unique only to aircraft," reports urbanairmobility.com. The eVTOL will have a range of 400 kilometers.

Following the flight, Honda is advancing to its full-scale validation phase. U.S. Federal Aviation Administration (FAA) certification for the eVTOL's airframe and engine has already been achieved per a Dubai Air Show 2025 briefing.

A 2030s service into entry targeting intercity passenger transport to complement business jet and helicopter use case has been reported.

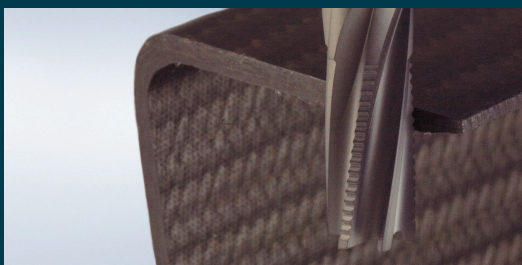


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GKN Aerospace's ASPIRE Program Targets Next-Gen Composite Wing Manufacturing Technologies

The 3-year, £12 million ASPIRE consortium brings together rapid tow shearing, tailored fiber placement, aligned recycled discontinuous carbon fiber and self-heated tool curing to prove lighter, high-rate composite wings for the next-generation single-aisle aircraft.

By Stewart Mitchell / Contributing Writer



» Somewhere in GKN Aerospace's (Bristol, U.K.) Global Technology Centre, there is a composite technician hand-rolling carbon fiber prepreg into what are known as noodles. These are individual sections nearly a meter long, shaped into a slender, triangular cross-section to become a deltoid filler that occupies the three-way radius joint where a composite spar or rib mates with the skin it's stiffening. The technique, for all its precision, is not meaningfully different from what it was 30 years ago.

"The manual aspects of fabricating the noodles and other composite aerospace parts carry a weight in production far beyond the obvious," says Tony Lloyd, GKN Aerospace principal composite research engineer and ASPIRE technical lead. "A next-generation single-aisle [NGSA] aircraft will require between 1,000 and 2,000 meters of these noodles per airframe. If Airbus reaches its stated production ambition of between 60 and 100 single-aisle aircraft per month, hand-rolling becomes a genuine bottleneck as a single anachronism that holds back an otherwise advancing manufacturing system."

The noodle, in other words, is a symptom. The underlying condition is the composite aerospace industry's persistent dependency on manufacturing approaches conceived in a different production era — where fiber layups are locked into the classic $0^\circ/\pm 45^\circ/90^\circ$ quasi-isotropic conventions, autoclave pressure vessels are required for curing and manual preforming is necessary for geometries that automated deposition cannot easily reach. These defaults have produced extraordinary structures. They have also reached the practical limit of what they can offer in terms of production rate, structural weight and embodied carbon for the next generation of narrowbody aircraft.

This is the problem ASPIRE (Advanced Structural with Product Integrated AirframE) was established to address. Launched in May 2025 and running through April 2028, the £12 million program is led by GKN Aerospace and partly funded through the U.K.'s Aerospace Technology Institute (ATI, Bedfordshire), Innovate UK (Swindon) and Department for Business and Trade (London). Its five specialist partners — iCOMAT (Bristol, U.K.), Carbon ThreeSixty (Chippenham, U.K.), Lineat Composites (Chepstow, U.K.), Pentaxia (Derby, U.K.) and the University of Bath (Bath, U.K.) — each address a specific failure mode in the current composites manufacturing paradigm. What makes ASPIRE unusual is that all five technologies are being deployed simultaneously, against the same structural geometry, and tested under the same conditions so the cumulative effect can be measured rather than estimated.

Three variants, one test campaign

The structural backbone of ASPIRE is a set of three full-scale composite wingtip variants, all derived from the folding wingtip geometry that Airbus (Toulouse, France) expects to feature on its next single-aisle aircraft. This is a design that extends the total effective wingspan by approximately 10 meters while allowing the tip to fold for airport gate compatibility. Airbus has provided baseline load cases and geometric guidance while GKN Aerospace holds design authority for the ASPIRE project. All three variants will be structurally tested to ultimate load at GKN's Isle of Wight test facilities, the standard aerospace certification threshold representing 1.5X the maximum in-service load, with results expected in late 2027 and early 2028.

■ LEFT: A CAD rendering of the ASPIRE wingtip demonstrator with the upper skin removed, revealing the spanwise spars, chordwise ribs, aerodynamic skin panels and multi-bay root fitting at the fold hinge line. Source | GKN Aerospace

but with an optimized structural architecture specifically for bonding. The method for bonding draws on the outputs of MaBOND, a parallel U.K. program led by GKN that is advancing automated bonding methods for primary structures. Bonded construction reduces fastener count and part complexity and, if it passes ultimate load testing in a primary structure context, meaningfully advances the regulatory acceptance of bonded joints in single-aisle aircraft.

Variant 2 represents the current state of the art. It is a quasi-isotropic co-infused resin transfer molding (RTM) structure built using automated preform deposition, digital twin integration and GKN Aerospace's SmARTM processing. This variant is believed to be the best available today using the automated RTM cell

Variant 1 is a bonded assembly using more traditional build and design methods currently seen in aerospace

developed through the preceding ASCEND program. Pentaxia's JouleTool self-heated mold is integrated at this stage, providing low-energy, self-heated tooling for automated 3D preforming of the wingtip skins.

Variant 3 is where the existing rulebook is set aside. Nonstandard fiber angles, enabled by iCOMAT's rapid tow shearing (RTS) technology, replace the quasi-isotropic default in the skins and spars. Low-energy dry fiber forming feeds GKN's SmARTM process. Carbon ThreeSixty's stitched deltoid noodles manufactured from recycled carbon fiber (rCF) aligned through Lineat's aligned fiber forming technology (AFFT) process replaces the hand-rolled fillers. The University of Bath's probabilistic analysis tools provide the structural design confidence that will be needed before any of these approaches a production aircraft.

Alongside the three wingtips, ASPIRE is developing an optimized wing movable in the form of a notional flap demonstrator. The flap advances fast-cure thermoset prepreg-manufactured structures with RTS-optimized skins, tailored fiber placed (TFP) brackets and low-energy, out-of-autoclave (OOA) curing molds, with a key program milestone being the achievement of TRL 6 for fast-cure thermoset press-cured composite ribs. This builds directly on GKN Aerospace's experience producing A350 flaps at its Munich, Germany facility.

■ The ASPIRE consortium partners — GKN Aerospace, iCOMAT, Carbon ThreeSixty, Lineat, Pentaxia, the University of Bath and program manager Axillium — are clustered across the south and midlands of the U.K.

Source | GKN Aerospace



Stitching the noodle

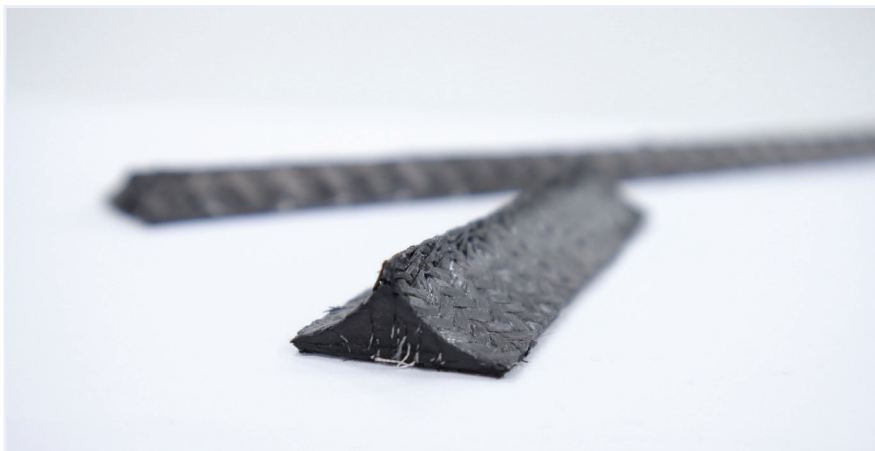
Carbon ThreeSixty brings more than 6 years of dry fiber TFP preform manufacturing experience to the deltoid noodle challenge. In TFP, which is essentially computer-controlled fiber embroidery onto a backing layer, the machine deposits fiber tow along a user-defined path, stitch-fixing it to the substrate and building up a near-net-shape preform without the cutting waste of conventional ply-based methods. The process has been proven across a wide range of structural preform geometries. For the ASPIRE project, the deltoid noodle introduces a specific new constraint where three knife-edge vertices converge toward a near-zero radius, each of which must be filled completely and held dimensionally through the infusion cycle.

"In previous applications, we've been doing all sorts of different shapes but not trying to go down to that kind of knife edge," notes Carbon ThreeSixty's technical lead, Sarthak Mahapatra. »

"What's different in ASPIRE is achieving a stable, precise fill of the deltoid corners in a format that stays dimensionally consistent right through to injection." The company has filed a patent on the resulting manufacturing approach, which it views as foundational to broader TFP noodle applications across the aerospace supply chain.

The fiber for those noodles comes from Lineat, a University of Bristol spinout producing AFFT tape made from a short fiber material in which rCF has been re-aligned along a common axis using a proprietary fluid dynamics process. To understand what makes this difficult, consider the analogy of papermaking: paper mills disperse fibers into a random, isotropic slurry precisely to produce a uniform sheet. Lineat's process does the opposite, driving alignment in a suspension of carbon fibers between 4 and 10 millimeters long and just 7 micrometers in diameter, producing a unidirectional (UD)-like tape from a discontinuous feedstock.

"The difference between a fiber being aligned and unaligned



■ Carbon ThreeSixty's TFP-manufactured deltoid noodle shows the triangular cross-section and stitch pattern that fills the three-way radius joint between a composite spar web and its flanges (above). A common skin-stiffener construction in the CAD-rendered ASPIRE wingtip demonstrator (right page) shows the deltoid noodle (in blue), which achieves a stable, precise deltoid filler for the joint between T-stiffeners and skin. Sources | Carbon ThreeSixty (above), GKN Aerospace (right)

affects the whole specification and property of that material," says Gary Owen, Lineat's commercial director. "Understanding those fluid dynamics at a 7-micron scale, knowing how the shape of a droplet hitting a plate affects the flow, knowing how each variable

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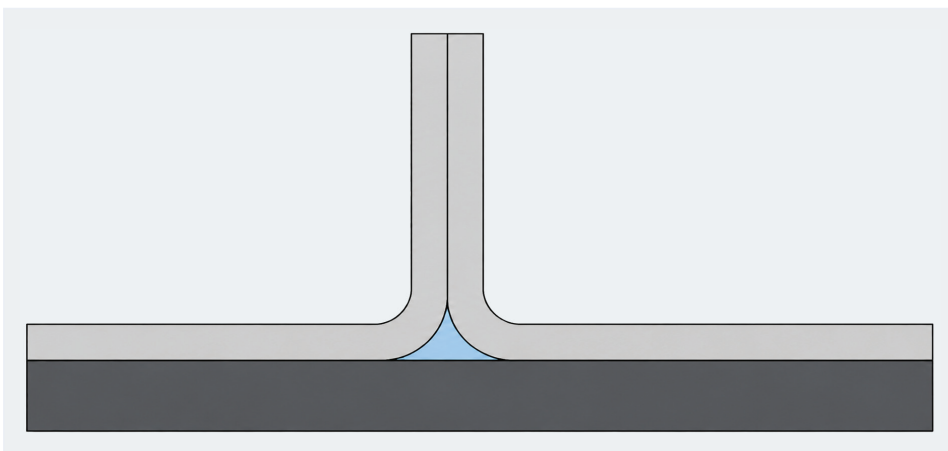
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that figure is specification. A noodle should not transfer primary loads between structural elements; its function is void filling and local compressive stiffness at the radius joint. A continuous fiber running the full noodle length would intercept structural loads in the joint unpredictably, complicating the design of the spar geometry around it. Lineat's short, aligned fiber architecture prevents that load path by design while still providing the stiffness needed to

interacts and validating the alignment of the material — that's where the real complexity is."

The resulting AFFT-aligned fiber tape is stabilized with an acrylic binder, compatible with standard thermoset and thermoplastic matrix systems. Lineat's pilot line can produce 1,000 meters of 100-millimeter-wide tape per day that scales substantially when the tape is reformatted to noodle-feed width.

Critically, the AFFT tape retains approximately 80% of the stiffness of virgin UD carbon fiber, and for the noodle application,

resist void collapse under infusion pressure.

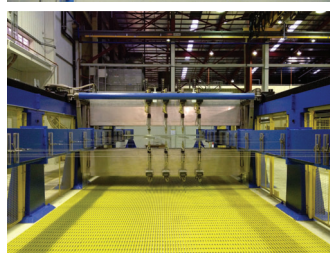
The same AFFT tape may carry a second function in ASPIRE. Pentaxia is currently investigating whether Lineat's recycled discontinuous fiber could serve as the heating element within its self-heated JouleTool molds. Carbon fiber is conductive, which makes it an attractive candidate for joule heating, but standard UD carbon fiber has low electrical resistance, demanding high currents at tool scale to generate sufficient heat. The short fiber breaks inherent in Lineat's aligned discontinuous tape introduce »



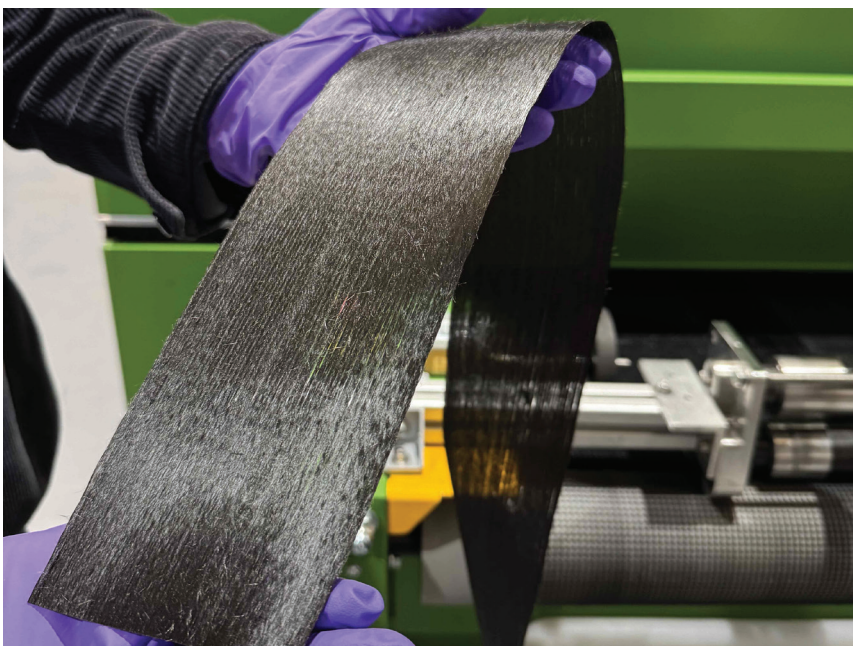
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■ Lineat's AFFT tape is produced by re-aligning recycled short carbon fibers into a common axial orientation to achieve approximately 80% of the stiffness of virgin unidirectional (UD) carbon fiber. Source | Lineat

resistance discontinuities throughout, increasing total resistance and reducing the current requirement. It is an unplanned synthesis between two partner technologies, and one that could simplify the company's JouleTool's electrical architecture considerably.

Steering the design

ICOMAT's RTS technology (see Learn More) places fiber tows at nonstandard angles by shearing the tow width rather than bending the tow path. This eliminates the gaps and overlaps that conventional automated fiber placement (AFP) introduces above approximately $\pm 30^\circ$ from the primary deposition axis, and delivers a continuous, defect-free fiber architecture at orientations that AFP cannot achieve. The result is a vastly expanded design space, so rather than selecting from the three standard angle families, a designer working with RTS can specify any in-plane fiber direction at any point on the laminate surface.

For the ASPIRE wingtip skins and spars, this creates two simultaneous opportunities. Structurally, fibers can be continuously routed around access panel cutouts and geometric discontinuities, maintaining uninterrupted load paths where quasi-isotropic laminates would rely on local reinforcement overlays. In terms of manufacturability, pre-optimized fiber steering can counteract the wrinkling modes that develop when a flat laminate is drawn over a complex tool surface during forming, reducing defect initiation without adding post-cure rework. For the flap, iCOMAT's team is addressing a more demanding geometry, where GKN Aerospace's engineers self-identified a waffle-pattern internal structure which has a corrugated topology with frequent tight-radius folds as a forming challenge that conventional AFP could not resolve. RTS is

being applied to define the fiber paths that enable that structure to be formed cleanly from a flat preform.

"There's no easy way of designing variable-angle laminates using classic engineering rules," explains Olivia Stodieck, iCOMAT's director of composites engineering. "You need optimization algorithms that can handle the complexity, and then you need to communicate the design intent in a form your manufacturing partner can integrate directly into their tools." A dedicated ASPIRE work package is building that integration layer linking iCOMAT's RTS design and simulation environment with GKN Aerospace's structural analysis tools so that fiber angle optimization and structural verification happen in a shared digital space, rather than sequentially across an interface.

The University of Bath provides the analytical foundation to give confidence in the nonstandard angle composite designs. Professors Richard Butler and David

Williams lead Bath's contribution, drawing on a 15-year structural research partnership with GKN Aerospace that has involved more than 20 Ph.D.s, an EPSRC program grant (CERTEST) on composite certification and now an EPSRC prosperity partnership (ZENITH). Bath is developing analytical and numerical methods to take advantage of the design freedom given by nonstandard fiber angle composite laminates. These methods, in areas such as formability, damage tolerance, aeroelasticity and noodle performance, will provide input to the design process of wingtip Variant 3. The aim is to gain a deeper understanding of how these nonstandard angle laminates can be used most effectively to reduce weight while retaining performance and manufacturability. There is also a need to provide a route to increased use of analysis-based certification for these laminates.

"Because you're freeing up the design space, it will be impossible to test all permutations," says Butler. "The challenge is creating confidence in the analysis method so that it can become a tool for certification and something regulators can accept as a valid basis for approval without requiring a test campaign that could never be completed."

The University of Bath has already engaged both the FAA and EASA in early discussions about analysis-led certification pathways for nonstandard angle composites. ASPIRE Variant 3's structural test results will be the first primary structure validation data those conversations can draw on.

Cutting the energy bill

Autoclave curing is the energy-dominant step in composite wing manufacture, and for components at wing-structure scale, it is also



■ An engineer operates iCOMAT's rapid tow shearing (RTS) deposition head mounted on a six-axis ABB robot at the company's Gloucester facility. Source | iCOMAT

the scheduling bottleneck. Pentaxia's JouleTool addresses both by embedding resistive heating elements directly within the composite mold tool, allowing it to generate and apply cure heat from a

wide, instrumented for RTM binder activation at 120°C, with a stretch objective of achieving 180°C cure for the advanced prepreg materials being used in the flap skins — around the thermal »

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standard electrical supply without the pressure vessel. The tool heats the part from the tool face outward rather than from the ambient atmosphere inward as it's the most efficient direction thermally.

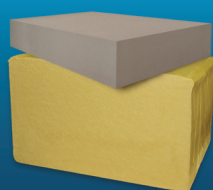
Pentaxia has been developing JouleTool through approximately 5 years of internal and commercial programs, and has demonstrated 80-90% energy savings compared to autoclave processing for large composite components. ASPIRE is the program that will take the technology to TRL 6 in an aerospace-scale, aerospace-quality manufacturing context. The primary deliverable is a lower wingtip skin preforming tool approximately 4 meters long × 1.5-2 meters

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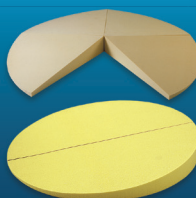
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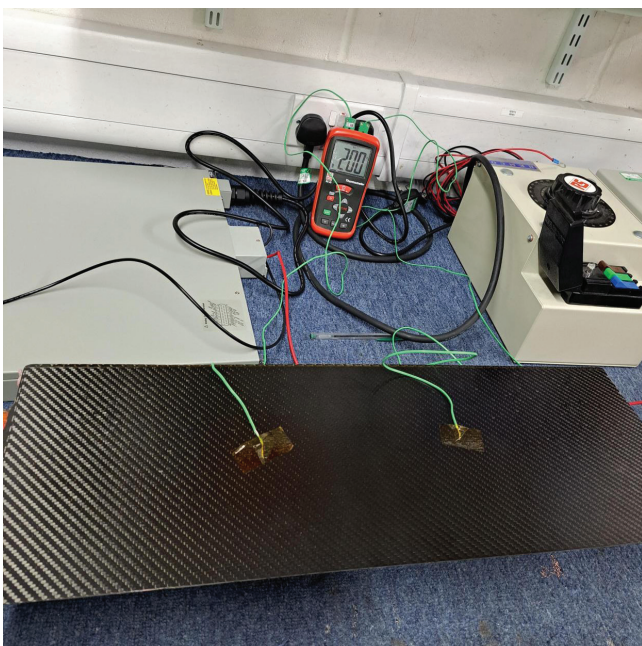
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■ A Pentaxia JouleTool test panel with embedded heating elements connected to a power supply, with surface thermocouples confirming a 200°C cure temperature. Source | Pentaxia

threshold for full prepreg consolidation and the most demanding condition the technology will face in a composite application.

“Our aim is that someone can give us their surface geometry and we can make a JouleTool package that suits their cure schedule and their component requirements,” says James Smith, business manager at Pentaxia. “The control unit has to be as familiar as an autoclave controller and enable automated cure input, scheduling and running.” The ASPIRE program control unit produces a digital twin output compatible with GKN Aerospace’s automated cell, making the JouleTool a native node in the digital manufacturing environment and enabling the real-time process monitoring that aerospace quality systems demand.

The heating element design itself remains in active development. Copper veil, which is the conventional material approach for internal heating, is effective but adds an extraneous material system within the composite tooling stack. UD carbon fiber as a heating element offers material consistency but generates low resistance, demanding high currents at tooling scale. The Lineat AFFT tape route would introduce a material that is already qualified within the program, provides tuneable resistance through fiber length and alignment density, and carries a sustainability benefit through its recycled feedstock. The ASPIRE

program will determine which route offers the most robust engineering solution.

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program will determine which route offers the most robust engineering solution.

Demonstration to test

The value of testing all three wingtip variants to ultimate load, rather than to a sub-scale coupon program or finite element predictions alone, is that the aerospace industry only has one currency for certification: physical evidence at relevant scale. All three variants are built to the same Airbus-derived geometry and tested under the same load cases. The weight differential between variants will be measured directly. More significantly, if the University of Bath’s probabilistic analysis tools correctly predict the structural behavior of Variant 3, ASPIRE will have demonstrated a route to certify nonstandard angle composite structures that the current regulatory framework does not yet accommodate.

ASPIRE follows the ASCEND program (Learn More), which concluded in March 2025 and established the manufacturing infrastructure of automated RTM cells, high-rate prepreg systems, digital twins and sustainability frameworks on which several ASPIRE technologies are directly built. Where ASCEND asked how to produce composite structures faster and more consistently, ASPIRE asks what a genuinely reconceived structure looks like when those production capabilities are already in place. The two programs are sequential arguments in the same case: that the U.K. composites industry has the knowledge, the supply chain and the physical evidence to lead the next generation of commercial aircraft structures.

“We’re not just trying to make things a bit lighter or a bit cheaper,” says GKN’s Lloyd. “We want to show that if you think differently about composites, if you use different design rules, recycled materials and better tooling, and then you test it the same way you’d test anything going on an aircraft, then you can achieve genuine benefit. Numbers on paper don’t move the aerospace industry. Test data does.”

By April 2028, ASPIRE will have produced the three ultimate load tested wingtip structures and an advanced movable wing, all built using technologies that today’s design and certification standards do not fully describe. That gap between what the tests will have shown and what the rulebooks currently allow is precisely what this program is designed to bridge. **CW**

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ABOUT THE AUTHOR



Stewart Mitchell is a Bristol, U.K.-based engineering journalist with experience covering technology in Formula 1, electric and hybrid powertrain and autonomous systems. He has a degree in motorsport engineering from Oxford Brookes University (Oxford, U.K.), and is a member of The Institution of Mechanical Engineers (London, U.K.). smitchell@compositesworld.com

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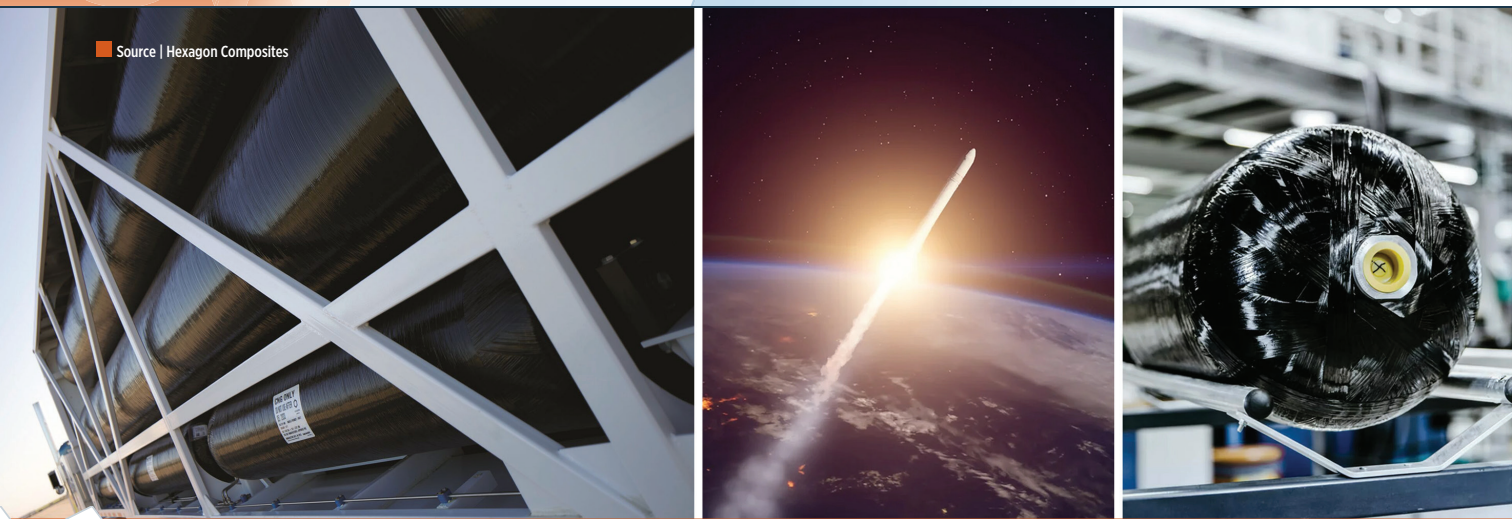
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The Future of CFRP Pressure Vessels: Larger Sizes, Lightweighting, Data Centers and Space

Hexagon Composites discusses the largest Titan 510 Mobile Pipeline, use of thermoplastic composites for lightweighting modules, towpreg, Chinese carbon fiber and growth from data centers and space.

By Ginger Gardiner / Senior Technical Editor

» Hexagon Composites (Ålesund, Norway) is a pioneer in Type 4 composite pressure vessels, which use carbon fiber-reinforced polymer (CFRP) filament wound onto a plastic containment liner to provide lightweight storage of compressed natural gas (CNG/methane), hydrogen (H₂), helium and other gases. These vessels and their integrated fuel systems provide lightweight, safe storage and transportation of clean alternative energies used in commercial mobility, bulk gas transportation and industrial applications. Building on 60 years of experience and innovation, Hexagon Composites has launched its largest commercial Type 4 composite cylinder manufactured to date, the Titan 510 Mobile Pipeline. It is reported to offer the highest capacity and operational efficiency for high-volume gas applications in industry, but also for energy, such as data centers.

Meanwhile, the company is re-entering the aerospace market, with its second \$5+ million order for high-pressure tanks for space, and sees potential for growth over the next 5 years. CW discusses these latest developments, as well as wet winding versus towpreg, issues in designing new Type 4 and metal liner Type 3 pressure vessels, newly added winding capacity and potential for growth.

History of Mobile Pipeline

Although Hexagon Composites was formed in 2000, its history in Type 4 composite pressure vessels goes back much further. In 2003, it acquired Raufoss Fuel Systems (Raufoss, Norway), which delivered its first Type 3 cylinders for CNG vehicles in 1992 (these switched to Type 4 in 2006). Hexagon then acquired what became Lincoln Composites (Lincoln, Neb., U.S.) in 2005. Founded in 1963 and previously part of Brunswick Defense and then General Dynamics, this facility produced filament-wound rocket motor cases and other defense components as well as composite-overwrapped pressure vessels (COPVs) for aerospace, including Skylab and the Space Shuttle. By 2010, Lincoln Composites had more than 180,000 Type 2, 3 and 4 pressure vessels in service, ranging in volume from 0.065 to 8,500 liters with operating pressures from 35 to 1,725 bar.

“In a lot of ways, that 60-year history and expertise from aerospace still drives our technology,” notes Chet Dawes, senior vice president of global engineering R&D for subsidiary Hexagon Agility (Costa Mesa, Calif., U.S.), the fuel systems supply division of Hexagon Composites (see Hexagon history infographic at right). “Lincoln continues to develop our most advanced manufacturing processes, which have informed the newest facilities in Kassel, Germany and Salisbury, North Carolina. It’s also where Hexagon pioneered Mobile Pipeline.” In 2010, Hexagon Composites’ Lincoln campus commercialized the first Titan product — an 11.6-meter-long, 1.1-meter-diameter Type 4 pressure vessel operating at 250 bar with a water volume of 8,400 liters.

Before Titan, Hexagon had developed what are today termed multiple element gas containers (MEGC). “Those were relatively small capacity, such



■ Hexagon’s Titan 510 Mobile Pipeline modules offer improved maneuverability and use thermoplastic composite (TPC) panels to cut nearly 2,000 pounds of weight for improved payload capacity. Source | Hexagon Composites

as a 20-foot container with 20 cylinders,” notes Dawes. “As we started to understand the worldwide demand, we pushed to develop the largest cylinder we could make that would fit in a 40-foot container. That led to the original Titan development, which was the largest pressure vessel in the market at that time. However, no codes or standards existed for a pressure vessel of that size, so we had to develop those as well, which resulted in an approval process and special permit by the U.S. DOT and Transport Canada, which then spurred the virtual pipeline industry.” Today, Hexagon has more than 2,250 gas distribution modules in operation worldwide.

Mobile Pipeline has since been through iterations of development, including a reduction in the amount of carbon fiber thanks to more efficient use, says Dawes. “In 2023, we launched our Titan 450 family of 46-inch-diameter cylinders using our latest state-of-the-art technologies for manufacturing at scale that we’ve continuously developed. We then again looked at how far we could go in size, which led to the Titan 510 — currently the largest Type 4 cylinder in production.” Launched in May 2026, the Titan 510 is optimized for 80,000-pound gross vehicle weight limits in the U.S. and Canada, also meeting the more restrictive bridge formulas in California.

Payload, simplicity, thermoplastic composite panels

The market driver for the Titan 510 was to maximize payload and to minimize length for maneuverability, explains Dawes. “The previous Titan 53 »



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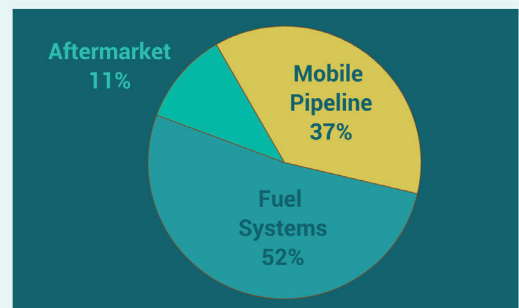
Type 4
composite
cylinders
produced

29

Homologated
OEM platforms
with Hexagon
fuel systems

100,000+

Vehicles on-road
with Hexagon
cylinders/
fuel systems



2000 Hexagon Composites

2016 Hexagon Agility

Formed via acquisition of Agility Fuel Solutions. Provides Type 4 cylinders, integrated fuel systems and Mobile Pipeline for CNG, RNG/biogas, etc.

2018 Hexagon Digital Wave

Formed via acquisition of Digital Wave. Provides cylinder monitoring and testing using modal acoustic emission (MAE) including for required 5-yr recertification.

2020 Hexagon Purus

Formed via spin-off of zero-emission technologies. Provides Type 4 hydrogen cylinders, battery systems and integrated fuel cell and battery electric vehicle systems for mobility, distribution and refueling.

■ Source | Hexagon Composites, compilation by CW

module, which used 42-inch-diameter cylinders, was challenging to maneuver due to its 53-foot trailer. That extra length is no problem on the road, but the 45-foot length of the Titan 510 helps when you have to turn and park in crowded industrial settings in order to defuel and decant or refill with gas."

New composite cylinder developments were also integrated to help maximize payload while carbon fiber winding advancements improved manufacturability for this larger cylinder. "Plumbing, valves and connections were kept consistent so that customers can interchange modules and have no real difference in fueling/defueling operations," notes Devin Flemming, lead system design engineer at Hexagon Agility. "We also minimize the number of cylinders in a module for simplicity, which is important for our customers operating fleets of hundreds of trailers."

"It was very difficult at the beginning to meet all of the requirements," he continues. "We're fitting so much more tank into the space, so that adds weight as does the higher gas payload, and you need to distribute that properly across the axles. We looked at how to reduce weight in the steel frame yet still protect cylinders from factors like potential impact and UV radiation. We previously used a metal roof and sides, but for the Titan 510 we chose rigid composite panels. These are thermoplastic sandwich panels with glass fiber-reinforced skins that have an excellent strength-to-weight ratio, are very durable and save about 2,000 pounds." Hexagon

performs the assembly but sources the panels from a U.S. supplier.

In addition to static load testing, Hexagon completed hundreds of miles of dynamic testing on different roads and terrains. "We used more than 30 sensors to understand the full module and chassis system response and correlated that to our customers' use of the modules," says Flemming. "That helped us to better optimize other parts of the frame, and we're continuing to gather data for future iterations of Titan products."

"During this testing, they broke everything, including the tractor and trailer suspensions," notes Dawes. "But the modules remained unfazed, showing the robustness we've achieved in this engineering and new design."

Growth via data centers

Hexagon's development of the Titan 510 and further future products are part of its response to the growing market for energy to power data centers and industrial sites as the electrical grid struggles to keep up. "We anticipated the demand for high-capacity modules to increase," says Dawes. Indeed, customers like Certarus Ltd. (Calgary, Canada and Houston, Texas, U.S.) started announcing data center contracts in September 2025. These include 50 megawatts (MW) of power for a hyperscale project until it can connect to a pipeline, support for 135 MW of power generation via 200 CNG transport trailers coming online in 2027 and primary

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Future Titan products, bespoke composites

Dawes notes that although liner materials and forming methods remain the same across different sizes of Titan cylinders, the composite laminate is bespoke to the specific length and diameter. “The 40-foot and 45-foot modules have a completely different composite laminate design to satisfy the service pressure and other requirements,” he explains. “But it’s also important to maximize the speed of production. For example, the speed of fiber payout, winding and resin impregnation of the fiber are also different depending on the size of tank we’re producing.”

“We have decades of experience learning how to build different size cylinders,” adds Flemming. “For example, there’s a certain amount of air that you need to put in during winding to ensure the liner doesn’t collapse. There are many things that we just understand, and we do different trials with design validation tanks when we’re building these new units.”

“With these larger tanks, we’re solving for issues we haven’t yet experienced on smaller-size cylinders,” says Dawes. “And we take those lessons learned and use them to better optimize the speed of manufacturing for our vehicular tanks for CNG buses and trucks. We’ve made all kinds of improvements in production and design from this kind of collective

learning across the different applications for our cylinders.”

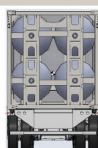
Manufacturing speed, towpreg, carbon fiber supply

Regarding speed of manufacturing, most new entrants to the Type 4 cylinder market are using towpreg — where the carbon fiber (typically 24K tow) is pre-impregnated with epoxy resin, heated to partial cure and then stored or shipped for winding — versus wet winding where dry fiber is pulled through a resin bath before being applied to the cylinder. These new tank producers claim that winding with towpreg is faster.

“We’ve evaluated towpreg,” says Dawes. “For those new to filament winding, towpreg makes sense because you don’t have to figure out how to do the impregnation — that’s already been done. But when that towpreg is made, the speed with which they impregnate the fiber is still very slow. That process can also damage the fiber during unspooling, impregnating and rewinding back on a spool, with numerous touch points and bends that can break some of the thousands of filaments in the tow.”

»

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Gross Module Weight (incl. gas)	33,300 lb	40,000 lb	50,000 lb	58,200 lb
Container Dimensions (L x W x H)	Coming soon 24.5' x 8.5' x 9'	40' x 8.5' x 9'	40' x 8.5' x 9'	45' x 8.5' x 9'



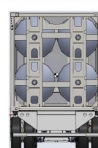
4 cylinders



3 cylinders



4 cylinders



4 cylinders

■ Certarus is using Hexagon Mobile Pipeline modules to provide power for data centers to start operations, avoiding delays while waiting for pipelines and grid connections. Sources | Hexagon Composites, Certarus

CNG supply for a 60-MW data center in Utah. The gas Certarus and other Hexagon customers deliver powers turbines, microgrids or behind-the-meter plants, providing the electricity required, and can be deployed in months, not years. Once connections to

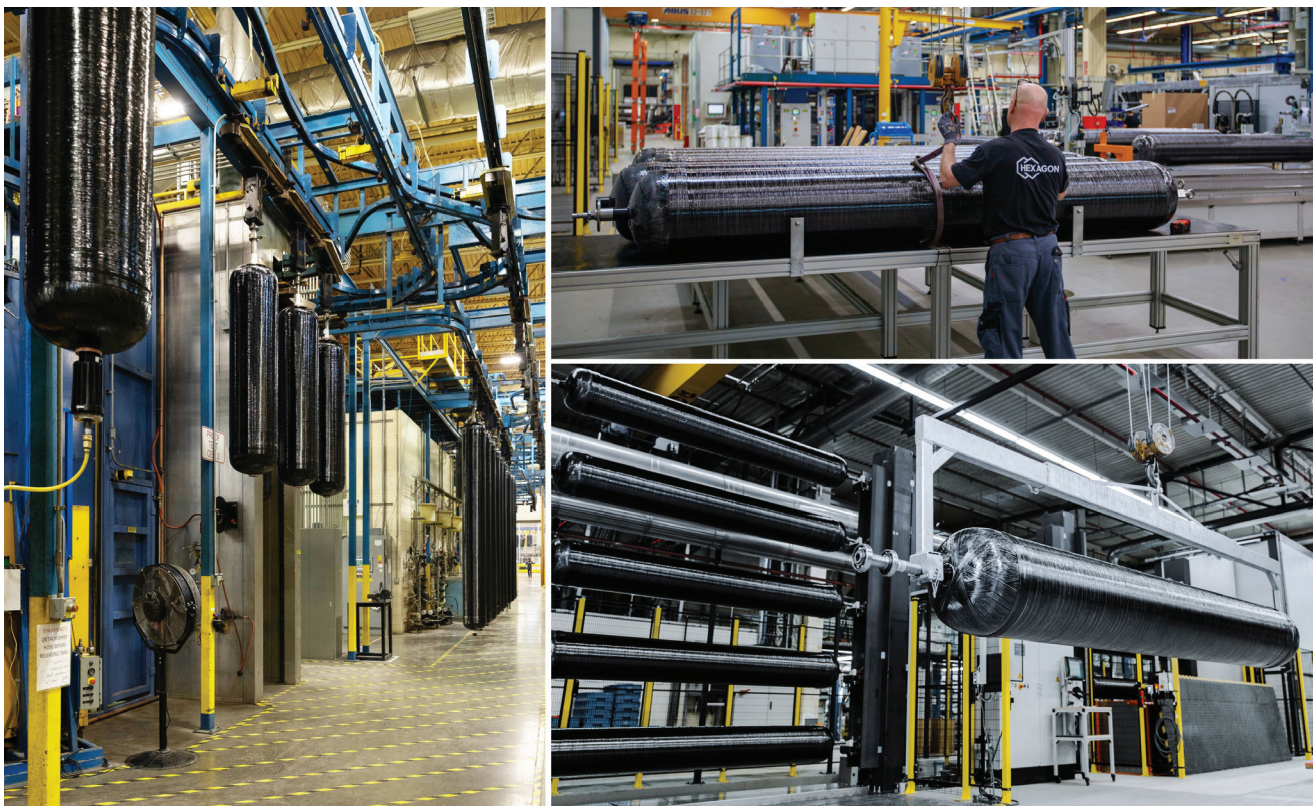
pipelines or other infrastructure are achieved, a subset of modules can remain to provide a buffer fuel supply and redundancy to eliminate risk of downtime.

“Whether it’s a data center or a major industrial site, both demand high capacity,” Dawes continues, “as well as assurance of reliable energy supply, and that’s what our Mobile Pipeline products enable. We’re continuing to develop new Titan products, including an even shorter-length version that’s due out soon,

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“By using wet winding, we handle the fiber once — unspooling, impregnating and winding in one continuous process — which results in less damage. This means less knockdown in fiber properties and more efficient use of the carbon fiber in the cylinder laminate. It also allows us to tailor the speed of manufacturing to optimize the impregnation — which we’ve developed over decades — according to the tank size and requirements. But if you don’t have that experience, then you can start winding very quickly with towpreg. However, it’s also more expensive than buying unimpregnated 24K fiber.”

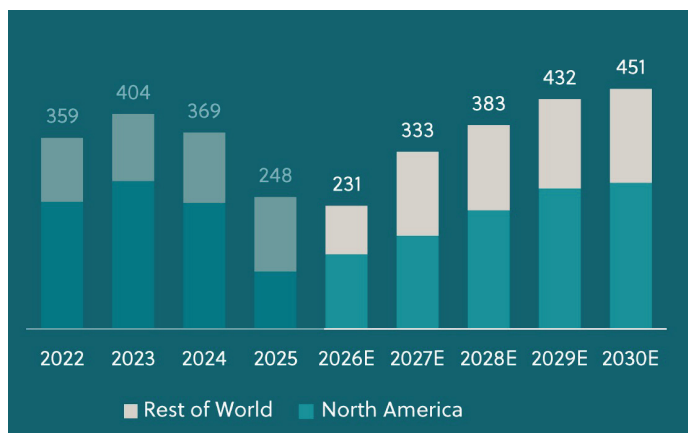
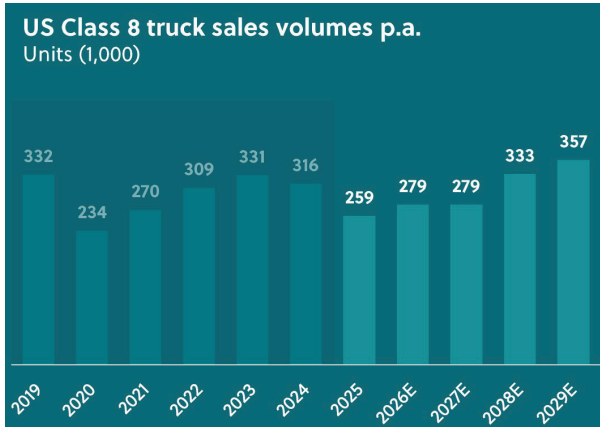
Regarding carbon fiber supply, Philipp Schramm, CEO of Hexagon Composites, notes that Hexagon is the largest consumer of fiber for pressure vessels, and one of the top three direct buyers of industrial carbon fiber globally. “We maintain relationships with all major carbon fiber suppliers to ensure access to the latest market developments and testing of new products. We source from multiple established suppliers of high-grade carbon fiber. While we do not currently source carbon fiber from China, we are closely monitoring developments there, which we see as a potential future market disrupter.”



■ At top, Type 4 CFRP cylinder production in Hexagon Composites’ Lincoln, Nebraska facility (left) and for Mobile Pipeline in Kassel, Germany (bottom right). At bottom, two composite cylinder production lines have also been added at the Hexagon Agility facility in Salisbury, North Carolina, to meet growing demand for CNG/RNG fuel systems in refuse vehicles and Class 8 trucks. Source | Hexagon Composites

Adding capacity for growth in CNG trucks

Hexagon Composites’ expertise in wet filament winding and Type 4 tank production has been developed mainly at its Lincoln,



■ Projected recovery in Class 8 trucks (left), along with growth in Mobile Pipeline and aerospace markets, supports Hexagon's positive outlook for its addressable market to 2030 (right). Source | Hexagon Composites

Nebraska, campus which includes three manufacturing plants: One is dedicated for Titan products, another has a wide variety of cylinder size and production capability and the third is a flexible production line featuring the latest in state-of-the-art technology. This, Dawes explains, is what the newest Hexagon Agility production in Kassel, Germany, was modeled after, which also influenced the new Hexagon Purus (Oslo, Norway) facility in Kassel and an extension of that has recently been added in the Salisbury, North Carolina plant.

As explained in CW's 2025 plant tour of the Hexagon Purus facility in Kassel, this flexible cylinder production line is set up in more of a circular or horseshoe shape to maximize production capability in the minimum footprint. "It also features two adjacent winding machines," says Dawes, "with the rest of the plant optimized

around those and operating as a single line. But it's also expandable to be two complete production lines and there is space to add two more replicates — so a total of six winding machines could operate in Salisbury. However, that second and third line are not yet configured and could be larger or smaller, depending on what's needed. So, we have invested in large-scale filament winding that is ready to scale with demand."

This new production will supply Type 4 cylinders for the Salisbury site's integrated CNG and renewable natural gas (RNG/biogas) fuel systems for heavy- and medium-duty trucks. Although new natural gas vehicle (NGV) registrations declined by 15% in 2025, The State of Sustainable Fleets annual report notes new *refuse truck registrations* increased by 27% with a growing share powered by RNG/biogas.

"After years of growth, 2025 saw a cyclical downturn in our core markets," says Schramm, "that was heightened by tariff volatility, unclear regulatory policy and macroeconomic uncertainty. »

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The Coming Surge in Space Launches & Vehicles

Orbital launches, active satellites, and the vehicles driving growth · 2020-2035

324

orbital launches in 2025
+25% vs. 2024 record of 259

967+

projected launches / yr by 2035
~3X today's record pace

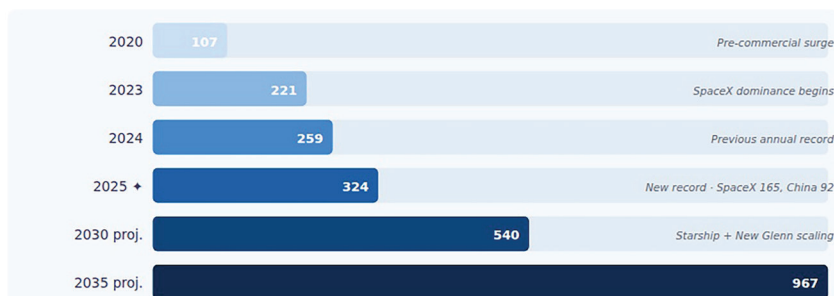
43,000+

active satellites projected by 2032
vs. ~10,400 active in 2024

KEY LAUNCH VEHICLES IN SERVICE OR DEVELOPMENT — 2025-2035

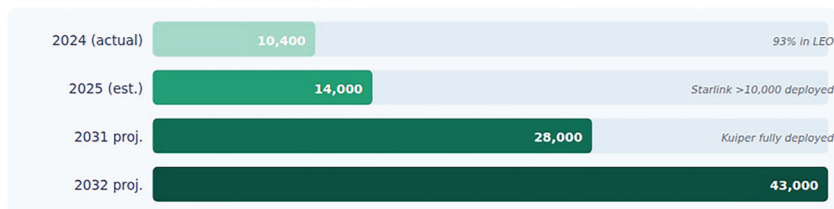


ORBITAL LAUNCHES PER YEAR — GLOBAL



+ 2025 is a confirmed record, 2030 and 2035 are ABI Research projections.

ACTIVE SATELLITES IN ORBIT — ACTUAL & PROJECTED



93% of active satellites orbit in LEO. Growth driven by Starlink, Amazon Kuiper (3,236 sats), and China's Guowang (13,000+ sats).

Source | CW with assistance from AI using multiple references, see article online. Note, these are only estimates to indicate trends.

2025, which has already resulted in an order for 100 CNG fuel systems for the largest trucking company in Mexico. Test trucks are outfitted with the X15N engine, matching the performance of traditional diesel engines but with up to 50% cheaper fuel costs. Hexagon has pilot programs with leading operators of 250,000-300,000 truck fleets including Walmart, UPS, Ryder and J.B. Hunt.

Growing market, reuse for tanks in space

“And now we’re again working substantially in the commercial aerospace field,” says Dawes, “and that’s also pushing the envelope of composite pressure vessel technology. The COPVs used here [typically Type 3 using metal liners] are under tremendous static and pressure loads, as well as dynamic and vibration loads during launch. If any one piece of that system doesn’t perform, the results can be disastrous.”

He notes that aerospace operates within a radically different design spectra. “A road trailer gets used for 15-plus years and cycled thousands of times, while space vehicle tanks have a much shorter life, even with reuse. The weight of Titan modules is indeed important, but nowhere near the emphasis it receives in aerospace. Also, we proof test every Titan at 1.5X its service pressure but it’s never operated near that. An aerospace COPV however, is constantly operating at 1.25X its service pressure and expected to rupture at 1.5X that. So, tanks for space are operating much closer to their limit than what is allowed for those in road trailers and vehicles, and they do this because every ounce you add creates a multiple in terms of

energy required to launch.”

But now with reuse, says Dawes, the holy grail in aerospace is to have durability in cycles and life expectancy closer to tanks for vehicular use, but yet retain the super lightweight, high performance needed for launch. “I do think there’s a growing market for COPVs in both commercial and defense aerospace, and they will need to be pressurized for longer periods of time. That will limit, to some extent, the loads they can maintain. If the pressure required is not high, then you’ll want to minimize the amount of carbon fiber used. So, the design problem is still very similar to what we face across all of our composite cylinders.”

“Meanwhile, the need for reliable quality becomes even more important with lower pressure, thin-wall tanks,” he continues. “The

The result was a 40% drop in our top line year-over-year. But our refuse truck and transit bus segments remained positive, thanks to trends that are continuing forward. Meanwhile, the heavy truck market is recovering.”

It’s also being driven by the Cummins (Columbus, Ind., U.S.) X15N engine, which entered full-scale production in late 2024. Sustainable Fleets 2026 noted that 71% of fleets using the CNG/RNG engine reported cost savings versus diesel and 38% intend to increase its use. Schramm notes that although less than 1% of the 300,000 Class 8 trucks sold annually in the U.S. use CNG, with the X15N, biogas and other trends, that is expected to increase to 8-10% over the next decade.

Hexagon Agility also launched a demonstration program in

higher number of layers you have, the more tolerance you have for transmitting load from one layer to another. But if you only have a few plies, then it's very important that they're perfectly laid and have the utmost quality. And the same is true with the input materials like the fiber. Just because a fuel tank for a satellite thruster is lower pressure doesn't necessarily mean it's a lower challenge. A super thin-wall tank is fragile, meanwhile you don't want to add any more weight than you absolutely have to."

This is where Hexagon's years and wide range of experience is valuable, says Dawes. "If you don't have experience in a wide range of real-world applications, then you may not understand how the design drivers change, including resistance to impact, vibration, thermal and mechanical stresses, plus operating in a vacuum environment. Each of these has unique challenges, but the COPV must also function on the Earth's surface during testing and filling, then survive launch and finally show reliability in orbit with no maintenance."

Flemming adds that Hexagon's design team is very adaptable with different types of requirements like this, including beyond the composite performance to gas flow or other operational aspects. "That system level expertise is needed to understand how to budget and control the amount of pressurized gas, whether that's helium, H₂, methane or others. We have a lot of experience in those areas across many different applications."

Not done pushing boundaries

"We learned a lot with our early cylinders for aerospace and truck applications, which we then applied to larger-scale Titan products," says Dawes. "Now, we're taking our most recent developments with larger-size cylinders and applying them in other markets, such as space, where rockets are getting larger and need higher gas capacity and durability while still maintaining the high level of performance and reliability that aerospace demands."

"We are building on the growing momentum across these markets," adds Schramm, "from the largest Mobile Pipeline cylinder for the Titan 510 modules, to breakthroughs in aerospace. Our focus is squarely on applying our technology and expertise at the scale and speed required to help our customer also push boundaries." **CW**



ABOUT THE AUTHOR

CW executive editor Ginger Gardiner has an engineering/materials background and more than 20 years of experience in the composites industry.
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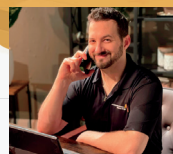
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Composite Liquid Hydrogen Tanks Without Carbon Fiber

Fabrum's 20 years of composites experience in superconductive systems has produced a patented triple-skin LH₂ tank design, proven in fast-fill testing and moving toward aircraft certification.

By Ginger Gardiner / Executive Editor

» Fabrum (Christchurch, New Zealand) has spent two decades building composite equipment for superconductivity applications — work that has positioned the company to become a leader in composite tanks for liquid hydrogen (LH₂). In late 2025, at its dedicated test facility at Christchurch Airport, Fabrum demonstrated rapid refilling of these tanks with less than 5 watts of heat leak, meeting industry requirements. This article is based on an interview with Hugh Reynolds, Fabrum co-founder and technical director.

Two decades of head start

Fabrum's origins trace back to superconductivity, where cryogenic liquids require nonmagnetic, sealed containment systems capable of withstanding pressure — essentially a vacuum flask engineered to aerospace-grade tolerances. The company spent 15 years developing composite equipment for these systems, including one of the world's first superconducting transformers with the University of Canterbury, learning in the process how porous composites can be if not manufactured properly.

That experience proved decisive once H₂ aviation emerged as a commercial prospect. As Reynolds explains: "If you don't have a need for this technology, then you don't spend time developing it. The true commercial desire for H₂-powered aircraft is only about 5 years old. So, if you started down the path to develop a composite LH₂ tank 5 years ago, you've only got 5 years of experience. But we've been doing it for 20 years because we wanted exactly

■ Fabrum has developed lightweight composite liquid hydrogen (LH₂) tanks for zero-emissions aviation and demonstrated fast filling with <5 watts of heat leak.

Source (All Images) | Fabrum

the same technology for our superconductors." Fabrum's head start also included a large-scale, real-world proving ground: an Australian mining company that wanted megawatt-scale fuel cells running on LH₂. The resulting 10,000-liter storage system used a more traditional metal dewar construction, in part because of the risk of impact damage in mining operations. But Reynolds notes Fabrum went from no one doing this to a system using up to 600 kilograms of LH₂ to power a 1.2-megawatt fuel cell with complex requirements on how it was dispensed. "We went with metallic tanks at that time, but we're now ready to replace those with composites."



First to demonstrate a working composite tank

Fabrum went on to demonstrate a fully functioning composite LH₂ tank — arguably the first to do so. “There were some traditional metal LH₂ tanks for mobility and perhaps some small-scale tests that showed a composite tank could hold LH₂,” notes Reynolds, “but we’re the only company or organization that I know of that’s actually demonstrated a full composite tank with fuel delivery system that can actually operate on a continuous basis.”

Getting there meant overcoming thermal shock, H₂ leak tightness and vacuum leak tightness, Reynolds explains, “where you don’t want the vacuum [in the space between the tanks] to decay. And then you have to be able to build such a system and make it affordable.”

“The one thing we didn’t have already was the ability to do a fast fill,” he continues. The solution was Fabrum’s patented triple-skin design: “We have a liquid containment vessel inside the pressure vessel made from a particular construction to handle the thermal shock during fast filling. But that containment vessel doesn’t have to handle the pressure loads, and therefore you’ve decoupled liquid containment and thermal shock from pressure capability. That was key and also provides redundancy should any incident cause loss of vacuum in the outer shell. You use vacuum there because it’s the

matrix cracking during the cooldown process for these cryogenic systems. So, we specifically design our laminates with other materials to avoid that problem.”

Instead, Fabrum builds fully composite tanks — with composite internal support structures — using metal fittings and a proprietary joining system, plus manufacturing techniques developed to eliminate the resin-void problems common to tightly bundled carbon fiber tows. Glass fiber with epoxy resin, refined over decades, is the material of choice. “For aircraft, composites are the only option” for weight savings, Reynolds notes, adding that some European aerospace groups have abandoned aluminum tank development because of weight and thermal penalties. And affordability is non-negotiable: “We come from an industrial background and understand our customers’ cost targets. We’re not trying to reinvent anything or use aerospace costing, and not using carbon fiber helps with that.”

Scaling toward aircraft and certification

The late-2025 fast-fill demonstration used a 180-liter tank storing 8-10 kilograms of LH₂. Fabrum has since designed larger 10-20-kilogram wingtip tanks for a six-seat general aviation aircraft, and expects twin 20-liter tanks to deliver 1-1.5 hours of flight time after reserve allowances.

Fabrum’s tanks have also demonstrated 20 hours of dwell time before venting is required, with a target of 40-60 hours. Fabrum expects to be flying three different aircraft with composite LH₂ tanks within 12 months, working with AMSL Aero’s *Vertiia* eVTOL and Stralis Aircraft’s H₂-electric Beech *Bonanza* retrofit, with certification of small aircraft targeted for 2030

— in line with the European Alliance for Zero-Emission Aviation (AZE) roadmap.

Reynolds acknowledges that carbon fiber will still be needed to meet 9G crash-load requirements for larger aircraft structures, adding there is knowledge in the industry to solve those issues. But Fabrum’s focus has been proving the harder problem first. “Getting the LH₂ fuel handling to work as needed, reliably and with an affordable, lightweight system — that was key.”

This article is an excerpt/summary of the full article available online at compositesworld.com. CW



■ A custom-built Fabrum double-skin LH₂ composite tank (left) for AeroDelft in the Netherlands, sits alongside Fabrum’s existing double-skin (center) and triple-skin (right) LH₂ composite tanks.

lightest weight, most effective insulation mechanism. But if that gets compromised, then you get a very high heat load onto your inner vessel, and the LH₂ is going to boil very rapidly.”

He reiterates the triple skin solves this issue. “Only 25% or less of the heat load gets into the LH₂, which means the rate we would have to vent in an emergency to prevent pressure buildup is substantially reduced. Our testing with LH₂ in real operating conditions shows that if you lost vacuum in flight, there’s actually no issue with continuing to fly. That was a key milestone as we move toward certification of our systems for several drone and small aircraft.”

Why no carbon fiber?

Fabrum has used carbon fiber, “but through our years of work with superconductive systems, we learned you’ve got to be very careful about system longevity. Carbon fiber’s high stiffness can cause



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DOE-Funded Researchers Developing High-Throughput, Low-Cost Carbon Fiber

The Carbon Fiber Design project aims to develop, and scale up with commercial partners, fibers with noncircular geometry optimized to meet compression performance needed for wind and other industries.

By Hannah Mason / Technical Editor

» Since 2020, the Carbon Fiber Design project — led by Oak Ridge National Laboratory (ORNL, Oak Ridge, Tenn., U.S.) with Sandia National Laboratories (Sandia, Albuquerque, N.M., U.S.) and Montana State University (MSU, Bozeman, Mont., U.S.), and funded by the U.S. Department of Energy (DOE) — has been developing cost-efficient carbon fiber that is performance-optimized initially for wind industry applications. Having achieved early promising results, the researchers are now seeking industry partnerships to scale toward commercial products in the wind market and beyond.

The project builds on more than a decade of ORNL work aimed at reducing carbon fiber production costs to enable wider adoption, including evaluation of lower-cost, readily available textile-grade polyacrylonitrile (PAN) precursor and advanced plasma oxidation (APO) developed with 4M Carbon Fiber (Knoxville, Tenn., U.S.). Those efforts produced fibers around 50% cheaper than current commercial fibers — but with compression strength 20-30% below the standard, an issue for the targeted application of wind blade spar caps. The Carbon Fiber Design project set out to increase compression strength by optimizing the shape and size of individual carbon fiber filaments.

Carbon fiber cross-sectional geometry: From circular to multi-lobed

Commercial carbon fibers are typically circular in cross-section, a shape that reflects the industry's historical focus on tensile strength for aerospace, as the symmetry offers processing consistency and favorable surface quality. But ORNL's textile-precursor investigations revealed a correlation between noncircular fiber shape and higher compressive strength in the final composite.

The mechanism, explains Dr. Brandon Ennis, materials and design lead, Aerodynamic Technology & Energy Systems department at Sandia, is a geometric property called the “area moment of inertia.” A noncircular filament has higher bending resistance than a circular filament of the same cross-sectional area, making it more resistant to the microbuckling that leads to compressive failure

in a composite — delaying the onset of failure and potentially improving fiber alignment.

An analytical study of fibers with different numbers and shapes of “lobes” concluded that three- and six-lobed fibers show

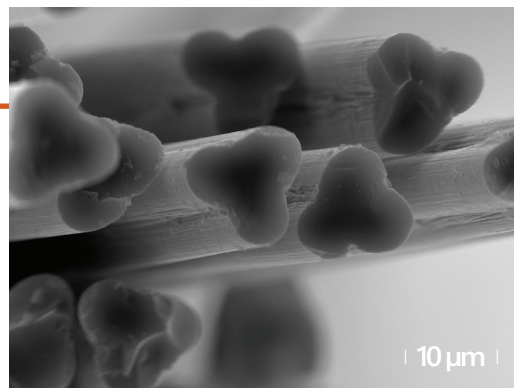
the most promise for cost and compressive strength, especially in applications requiring high fiber volume fraction.

Researchers then examined two aspects in parallel: the effect of filament size on compressive strength, and the best process for manufacturing three- or six-lobed fibers. Sandia contributed modeling, ORNL ran manufacturing trials — starting with custom-designed spinneret die holes to wet spin the target shapes — and MSU performed materials testing, iterating to control for geometry and mechanical performance.

Results: Higher throughput, lower production costs, increasing compressive strength

The project's manufacturing trials, material testing, simulations and cost models have led the researchers to pursue three-lobed fibers so far of up to 11 microns in effective diameter — the equivalent diameter for a noncircular fiber's cross-sectional area — versus the typical 5-8-micron range.

PERFORMANCE. The three-lobe shape has proven the most robust geometry in ORNL's trials, achieving fiber volume fractions close to 70% in infused samples. “If our observed correlation of compressive strength and fiber size holds as we increase in size, we expect to see slightly more significant increases in compressive strength for the geometries currently under development, which



■ This micrograph shows the project's three lobe diameter (versus typically circular) carbon fiber filaments, which are optimized for performance and cost targets. Source | ORNL

have fiber areas that are 2.5X that of circular fiber and a bending resistance that's around 9X higher," Ennis says.

FASTER PRODUCTION. The three-lobed fibers are also estimated to increase carbon fiber line throughput by 2-3X that of a typical circular fiber. The rate-controlling step in converting precursor to carbon fiber is the oxidation furnace, which is controlled by the fiber's diffusion thickness — the radius, in a circular fiber, or the distance to a plane of symmetry in a noncircular one. Circular fibers geometrically have the highest diffusion thickness per area, making them the worst shape for this constraint, Ennis says. A three-lobed fiber significantly reduces diffusion thickness for the same cross-sectional area, increasing line speed. And as fiber size increases to match the diffusion thickness of a circular fiber, line speed stays roughly the same while the larger fiber area doubles the throughput of a conversion line.

LOWER-COST PRODUCTION. Compared to a baseline commercial-grade carbon fiber, the project's approach can reduce production costs by up to 50%, depending on tow count, Ennis says. The throughput increase also cuts energy consumption, reducing energy costs during the conversion stage on the order of 40-50%.

Next steps: Continuing trials, scaling up

Sandia is continuing numerical modeling studies, including of other mechanical properties such as transverse performance.

ORNL is optimizing and scaling up its wet spinning process in order to supply larger test samples, and aims to work with carbon fiber manufacturers to evaluate company-specific PAN chemistries.

Despite past industry hesitancy toward changes in fiber or production characteristics, Ennis reports increasing interest. The project's advisory board now includes carbon fiber manufacturers alongside wind blade manufacturers and others.

"The goal is certainly commercialization," Ennis emphasizes. A separate DOE I-Corps program is aimed at developing a formal commercialization strategy, and part of that work, adds ORNL distinguished R&D staff member Bob Norris, is bringing other applications to the table to drive market pull. Potential areas include automotive leaf springs and bumper structures, pultruded infrastructure I-beams, drill risers and tension legs for offshore oil and gas, and interior aerospace floor or storage structures.

This article is an excerpt/summary of the full article available online at compositesworld.com. CW



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Technical editor Hannah Mason has been writing and editing about composites for *CompositesWorld* since 2018. She has a Master's degree in professional writing from the University of Cincinnati. hmason@gardner.media

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NEW PRODUCTS

» EV battery lid

Autoneum BEV Battery Lid Prototype Unites Multifunctionality and Composites

Autoneum (Winterthur, Switzerland) is debuting its novel composite battery lid prototype, a multifunctional component that simplifies battery pack design while meeting the key safety and performance requirements of modern battery-electric vehicles (BEV).

Functionally, the battery lid is conceived as a highly adaptable top cover for the battery pack. Its composite structure allows the integration of additional functional layers, such as flame-retardant (FR) layers or electromagnetic shielding, depending on vehicle and platform requirements.

“By consolidating functions that previously required multiple individual components — such as a separate battery lid and a flame shield — our solution reduces assembly complexity and effort,” says Luca Mazzarella, head of new mobility at Autoneum. “We can replace two or more parts with a single one.”

Manufactured using spray transfer molding (STM), the battery lid is glass fiber-reinforced polyurethane, offering high mechanical strength, formability for complex 3D shapes and tight radii, and thin part thickness for lightweight potential. The STM process achieves fast production cycles, design flexibility and 30% weight saving compared to traditional manufacturing methods.

From a safety perspective, the battery lid is a further development of Autoneum’s flame shield technology, achieving enhanced thermal and electrical insulation properties and improved thermal runaway confinement. Both the battery lid and flame shield are produced without mica, addressing sustainability and supply chain concerns associated with conventional flame protection materials.

Autoneum | autoneum.com



» Pre-dispersed graphene paste

HydroGraph Launches Pre-Dispersed Fractal Graphene Paste

HydroGraph Clean Power Inc. (Austin, Texas, U.S.) has commercially launched Fractal Graphene Paste, which delivers the company’s high-purity Fractal Graphene in a stable, highly concentrated, ready-to-use aqueous



graphene product designed to overcome a significant technical challenge associated with graphene adoption: achieving effective dispersion. It simplifies the integration of graphene into industrial formulations and can accelerate commercialization across multiple end markets.

“One primary challenge in incorporating graphene into fiber-reinforced composites is achieving a uniform dispersion throughout resin systems,” explains Tom Eldridge, HydroGraph director of business development. “Graphene powders tend to agglomerate, which can require specialized mixing equipment and additional processing steps before they can be incorporated into epoxy or other resin formulations. Rather than starting with dry graphene powder, formulators can integrate a ready-to-use dispersion like Fractal Graphene Paste into water-based systems using conventional mixing equipment. This can simplify formulation development, improve dispersion consistency and reduce processing complexity.”

Fractal Graphene Paste from HydroGraph contains 20% graphene by weight — making it one of the highest concentration graphene dispersions commercially available while remaining long-term stable, the company reports; comparable commercial graphene dispersions are typically available at concentrations of only 1-5% graphene. HydroGraph’s stabilization technology, combined with its ultrafine graphene morphology (D50 particle size of ≈ 35 nm), maintains long-term dispersion stability and prevents re-agglomeration during storage and processing, with a greater than 2-year shelf life. Fractal Graphene Paste is specifically designed for water-based systems.

HydroGraph Clean Power Inc. | hydrograph.com

» Dual-use coating

Cambium Introduces Dual-Use Protective Metallics, Composites Coating

Cambium (El Segundo, Calif., U.S.) presents ApexShield 3000, a high-temperature phthalonitrile coating engineered for metallic and composite substrates operating in extreme thermal environments. The coating supports applications from hypersonic flight to electromagnetic interference (EMI) and radio frequency (RF) shielding for electronics and commercial programs requiring wavelength-tunable performance.

ApexShield 3000 is a sprayable, solvent-based, one-part liquid that cures at temperatures as low as 215°C and delivers sustained operational performance up to 315°C, with short-duration capability up to 427°C. The system requires no refrigerated storage and is available in quarts, gallons and drums, supporting both prototype development and production-scale programs.

The coating accepts conductive and nonconductive fillers, enabling engineers to customize performance characteristics for specific program requirements.

"ApexShield 3000 gives engineers a practical, high-performance solution for protecting structures that operate in environments where standard coatings fail," says Cambium CTO, James Griffin. "The combination of

sprayable application, room temperature storage and validated high-temperature performance makes this a deployable tool for defense and aerospace manufacturers working under real production constraints."

ApexShield 3000 builds on Cambium's growing portfolio of phthalonitrile-based materials, including the ApexShield 1000 resin system, which reduced carbon-carbon (C/C) parts fabrication cycles by 70-80% for hypersonic applications.

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Release Films
Breather/Bleeder & Flow Mediums
Sealant (Tacky) Tapes
Pressure Sensitive Tapes
Release Liquids (Mold Releases)
Vacuum Connections, Hoses, Valves
Rubber Products

Tooling

Pre-Pregs & Surface Coats
Resins & Surface Coats
Cloth, Surface Veils & Filler Pastes
Machinable Master Systems
Tooling Back-Up & Support Structures
Polyurethane Foam Tooling Board

Technical Fabrics, Fiber Reinforcement

Fiberglass
Aramid
Carbon/Graphite
Quartz, Ceramics (Nextel™)

Core Material

Aluminum Honeycomb
Aramid Fiber Honeycomb
Polyurethane Foam
Ablative Cork

Pre-Preg

Fiberglass
Carbon/Graphite
Aramid

Non-Destructive Testing Products

Material Racks & Engineered Packaging Solutions

Aviation Products/Cleaners

Corrosion Inhibitors, Lubricants
Surface Preps & Cleaners
Electronic Cleaners

Adhesives

Engineered Adhesives
Epoxy Adhesives
Hot Met Adhesives
Film Adhesives
Foaming Adhesives

Abrasives

Pressure Sensitive Tapes
Masking
Duct
Specialty

Cleanroom Products

Sticky Mat
Gloves and Overalls

Polysulfide Sealants

Surface Prep Products for Bonding

Protective Paper & Film Tapes

Vacuum Pumps

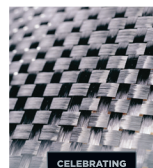
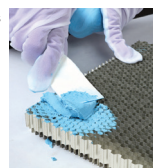
Mobile and Stationary Systems

Health & Safety Products

Protective Masks/Respirators
Reflective Products
Marking Products

Composite Repair Equipment

& Materials
Hot Bonders



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» Seawater desalination

Toray to Launch TSW-K/M/V Series Reverse Osmosis Membranes

Toray Industries Inc. (Tokyo, Japan) is launching the TSW-K/M/V series of advanced reverse osmosis (RO) membrane elements, featuring an outer GFRP composite wrapping, for seawater desalination in October 2026. Toray contends that this offering combines a salt rejection rate unmatched by competitors (as of May 2026), with benefits like boron rejection and high chemical resistance.

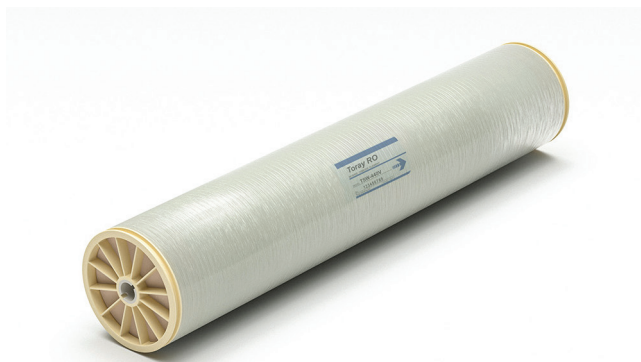
When a semipermeable membrane separates a concentrated aqueous solution from a dilute aqueous solution, osmotic pressure causes water to move from the diluted side to the concentrated side. RO applies pressure greater than the osmotic pressure to the concentrated side, so only water can pass through the membrane. RO membranes can remove salts, organic compounds, boron and other substances. They serve widely in seawater desalination, ultrapure water production and other applications.

Evaluations show Toray's RO membrane elements have salt permeability up to 55% lower than that of current Toray models (TM820M/TSW-M). New seawater desalination projects can thus switch from regular two-pass RO membrane treatment to a single-pass process. For

existing two-pass facilities, the series is able to save energy and improve water quality by alleviating operational loads on second-pass equipment and optimizing operating conditions.

This should help streamline overall water treatment and cut total operating costs, Toray says. The series also delivers high-performance boron rejection, and should limit membrane performance degradation during chemical cleaning.

Toray Industries Inc. | toray.com



» Online customization

BigHead Bonding Fastener Customization Targets Composites Design Challenges

BigHead Bonding Fasteners Ltd. (Verwood, U.K.) offers a bespoke online customization service that enables engineers and designers to modify standard bonding fastener products to meet the specific structural, environmental and assembly requirements of their composite applications.

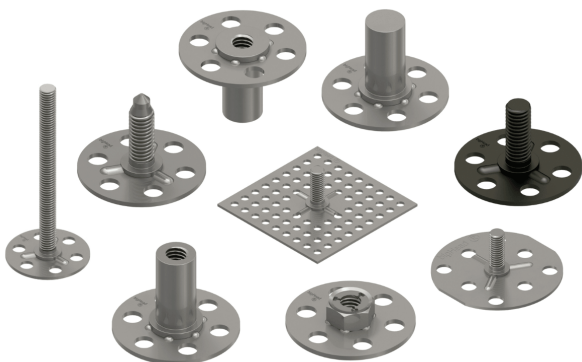
Thread and geometry options. Thread length variants allow stud and collar products to be adjusted in 1-mm increments — shorter variants reduce intrusion into

surrounding spaces, while longer ones increase thread engagement or span greater distances. ISO 4753 end-forms modify the tip of externally threaded studs to reduce cross-threading, prevent nut loss and support self-alignment during manual or automated assembly. For applications requiring broader load distribution, bigHead offers two enlarged head formats.

Collar and locking features. Three collar-specific customizations address sealing and installation performance. A closed blind collar pairs a blind head with a blind flange collar to create an airtight seal. A closed sighted collar provides similar fluid protection while retaining thread access through a sighted head. A reverse weld collar flips the standard weld orientation for applications where installation loads may exceed standard weld strength, or where a smooth mating surface is needed.

Surface finishes and coatings. BigHead also offers alternative finishes and coatings across most of its product range. According to the company, coating options address corrosion resistance, surface cleanliness, friction control and visual appearance requirements.

BigHead Bonding Fasteners Ltd. | bighead.co.uk/





Joe and Mark Annese

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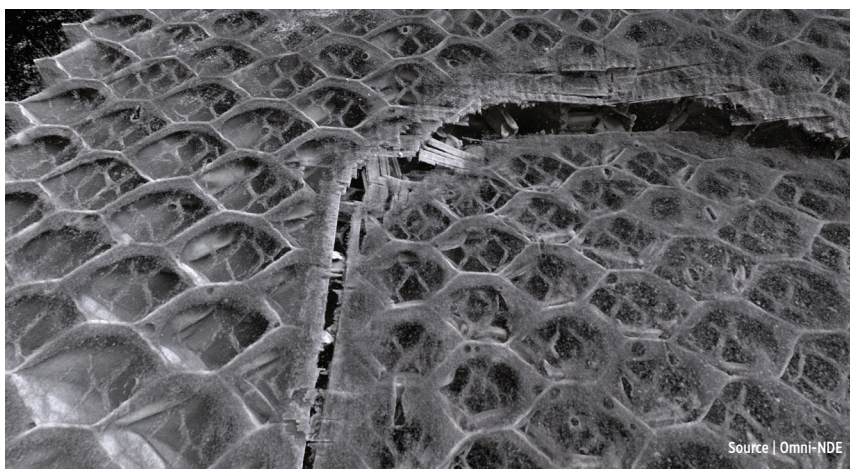
POST CURE

Highlighting the behind-the-scenes of composites manufacturing

Robotic Laminography Reveals Microscopic Impact Damage in CFRP Sandwich Panels

» Omni NDE's (Ogden, Utah, U.S.) robotic computed laminography system, a derivative of computed tomography (CT) scanning, captured this striking view inside a damaged honeycomb core carbon fiber-reinforced polymer (CFRP) sandwich panel. The resulting image reveals failure mechanisms invisible to conventional inspection methods. Notably, the 12-micron-resolution scan shows individual carbon fiber breakage, crushed aluminum honeycomb cells with

40-micron-thick septum walls and complex deformation patterns radiating from the impact zone. Unlike circular CT systems constrained by scanner size, Omni NDE's collaborative robots with X-ray-equipped end effectors bridge a critical gap for aerospace manufacturers. They provide volumetric inspection with 5-micron spatial



Source | Omni-NDE

LEARN MORE

Read more about this technology by scanning the QR code.



resolution even on large structures, and help engineers visualize bond line discontinuities, fiber damage, voids, delamination and more that ultrasound cannot always adequately characterize. This is especially important for enabling informed acceptance or rejection decisions on expensive one-off components. These systems also operate at 50-150 kilovolt peak for CFRP inspection, allowing deployment in standard facilities rather than dedicated concrete vaults like those required for dense metal CT scanning. **cw**

Show us what you have!

Every issue of *CompositesWorld* concludes with Post Cure, a section highlighting the behind-the-scenes of composites manufacturing.

The CW team wants to feature your composite part, manufacturing process or facility in an upcoming issue. Send an image and caption to CW senior managing editor Grace Stubbins at gstubbins@gardner.media.



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