

A white KUKA robotic arm is shown in a factory environment, positioned over a work area. The arm is labeled 'KUKA' and 'A5'. It is surrounded by various industrial components, including a blue conveyor belt and a large red dome-shaped object. The background is a plain grey wall.

Dome reinforcements for composite tanks

Fiber Patch Placement equipment & software
to produce 15% lighter composite tanks

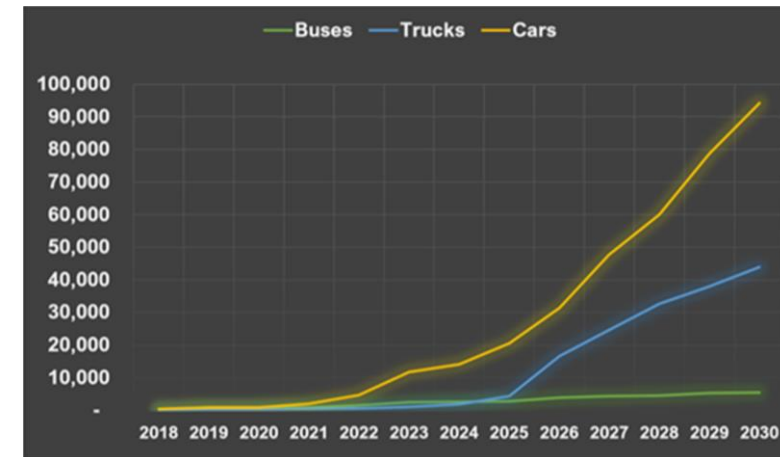
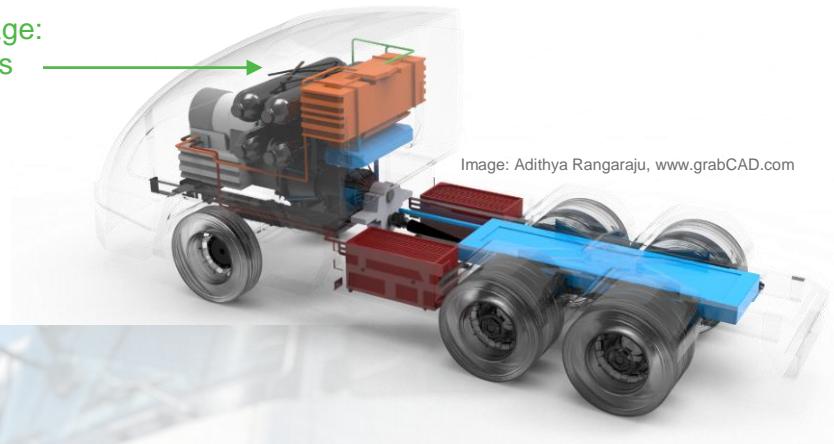
March 2024

cevotec
milestones in composites

Hydrogen-powered mobility drives demand for pressure tanks & carbon fibers

Hydrogen-powered mobility is growing fast. This drives exponential demand for composite tanks in the upcoming decade, creating significant competition and growth pressure for global carbon fiber supply.

Hydrogen storage:
composite tanks



	2030 FCEV Projection	2020 Vehicle Production	% of Current Production
Buses	17,633	270,000	6.5
HD Trucks	42,380	4,100,000	1.0
Cars	754,585	92,000,000	0.8

Projected CF demand 2030 composite tanks only: 130kt – 250kt

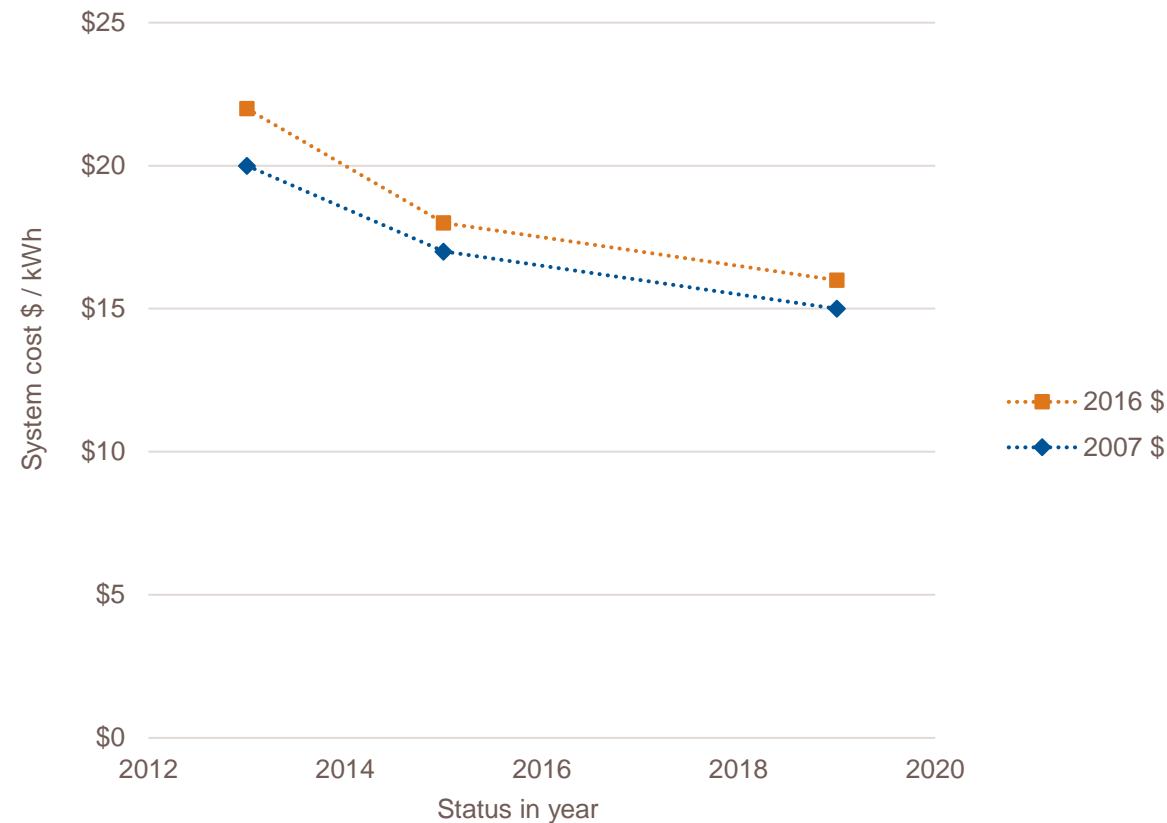
Compare with total global CF market today: approx. 100kt

Source: Composites World (<https://www.compositesworld.com/articles/the-potential-for-hydrogen-to-fuel-composites-growth-part-1>), September 24, 2021

System cost for mobile storage of compressed hydrogen

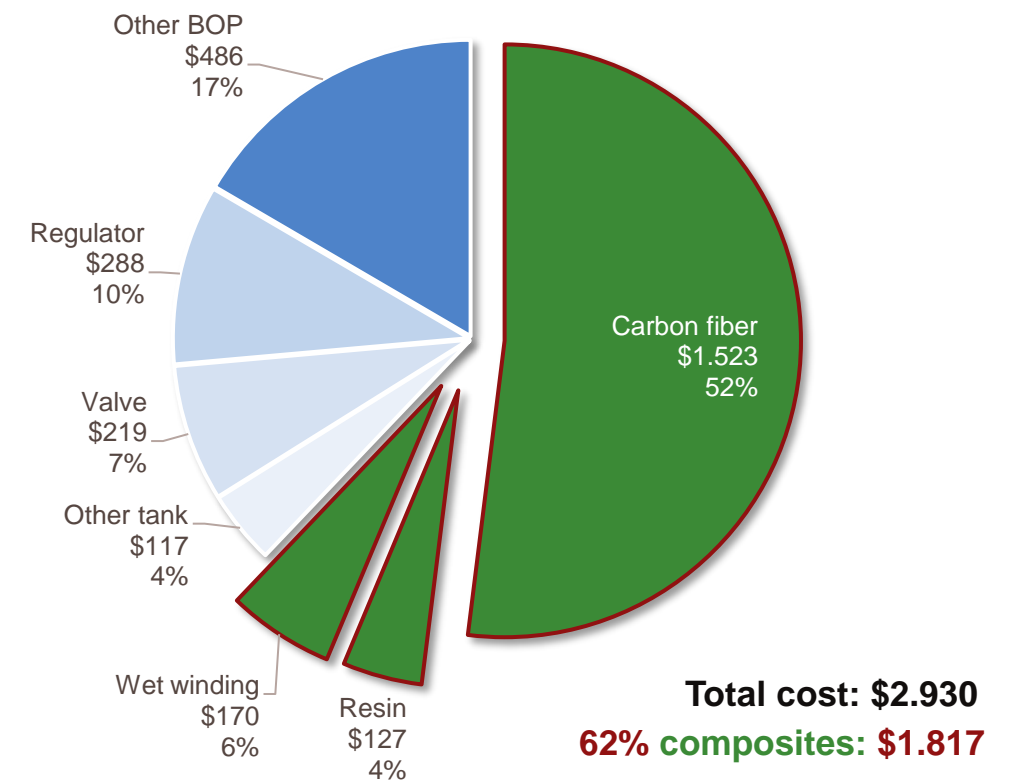
While storage system cost have decreased notably in the last decade, the composite shell is still the largest cost reduction opportunity, representing over 60% of total cost of storage system.

Comparison of storage system cost (2013, 2015, 2019)



Source: based on J. Adams, et al.; Department of Energy, USA; DOE Hydrogen and Fuel Cells Program Record, 2019

Storage system cost breakdown (100k annual production volume)

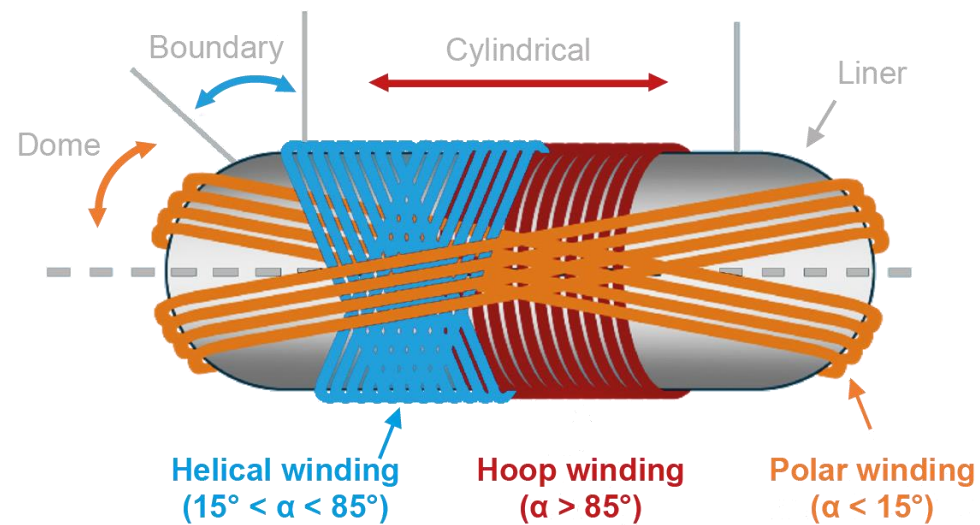


Source: based on J. Adams, et al.; Department of Energy, USA; DOE Hydrogen and Fuel Cells Program Record, 2019

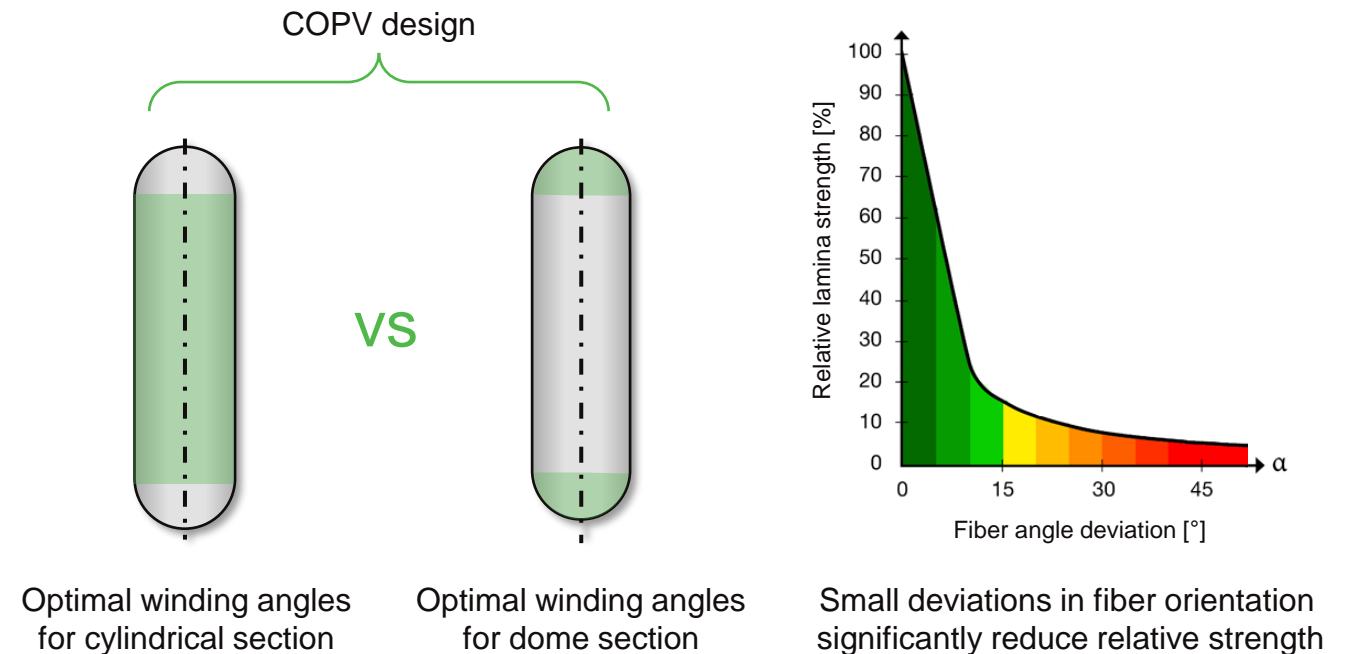
Fiber angle impact on performance

Certain helical winding orientations support the dome area and contribute only marginally to strength in the cylindrical section due to their orientation with angle deviation from principal load.

3 types of winding patterns in COPV



Key consideration for COPV laminate design

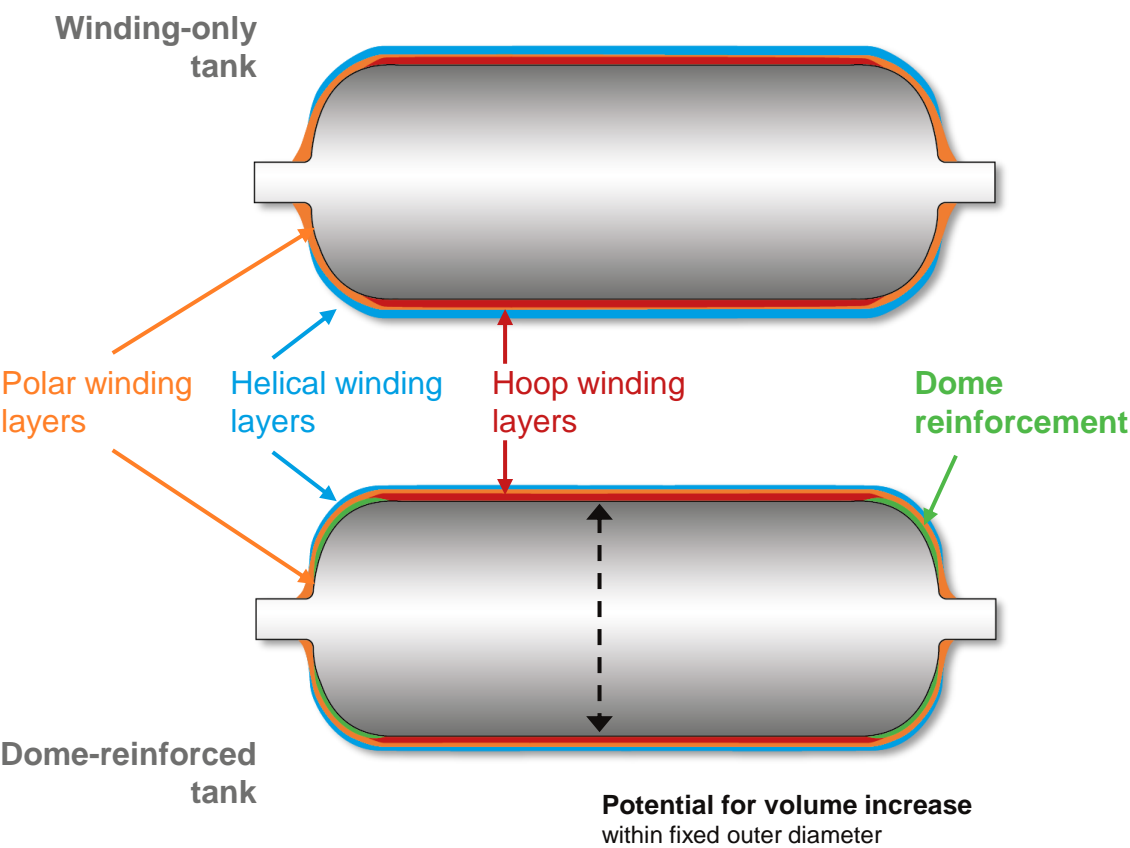


► Winding designs that are optimal for the dome region are not ideal for the cylindrical section.

Dome reinforcements for pressure vessels yield 15% material efficiency

The US Department of Energy proved 2015 that replacing high-angle helical layers by dome reinforcements reduces material consumption by 15% to achieve similar mechanical performance.

Replacing high-angle helical layers with reinforcements



15% material reduction opportunity – not seized yet (!)

“The ABAQUS model considers the use of “doilies” which are “strips” of carbon fiber composite placed strategically in the dome regions for local reinforcement. The **purpose of the doilies** is to **reduce the stiffness discontinuity** between the cylinder and dome sections, **and the amount of helical winding** needed to maintain the identical stress ratio as without the doilies.”

Source: S. McWhorter, et al.; Department of Energy, USA; DOE Fuel Cell Technologies Office Record, 2013

Table 3: Composite weight for tanks with and without doilies.

	Doilies	Weight (kg)			Total
		Hoop	Helical	Doilies	
2013 Baseline [2]	Yes	40.2	48.0	2.8	91.0
Calibrated Performance Model	No	34.3	72.3	N/A	106.6

Δ 14,6%

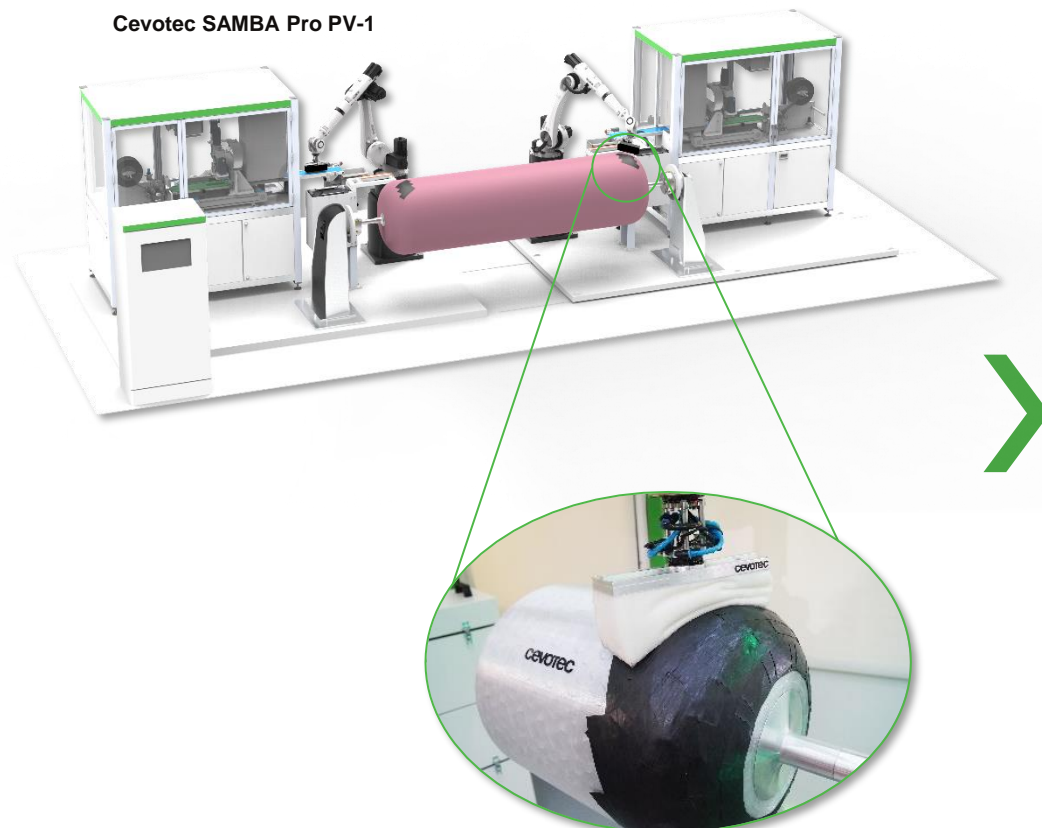
“However, **doilies were eliminated** from the 2015 tank design based on tank manufacturer **[bad] experience with manufacturability**. Doilies may **still represent an opportunity to reduce the carbon fiber composite**, but further work is required to demonstrate and **validate their manufacturability at high volume**.”

Source: G. Ordaz, et al.; Department of Energy, USA; DOE Hydrogen and Fuel Cells Program Record, 2015

Scalable solution for automated production of reinforced composite tanks

Fiber Patch Placement (FPP) is the first technology to place dome reinforcements directly on the liner. This enables an automated scalable production, combined with existing winding equipment.

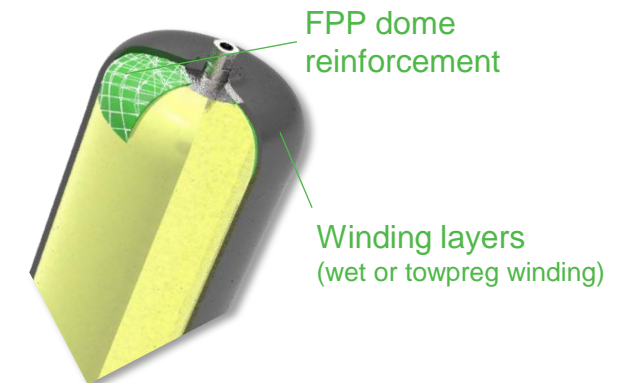
1 Automated liner reinforcement



2 Filament winding (less material)



3 Lighter composite tank



Illustrative savings potential¹

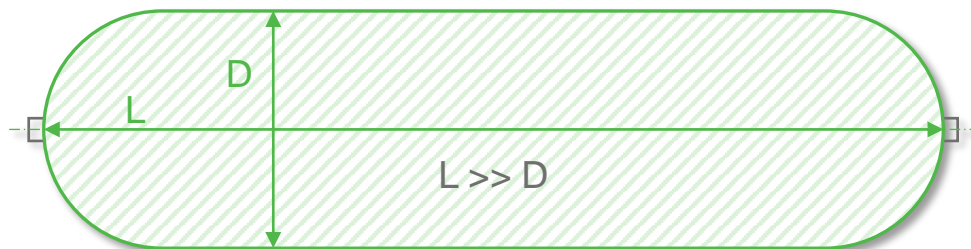
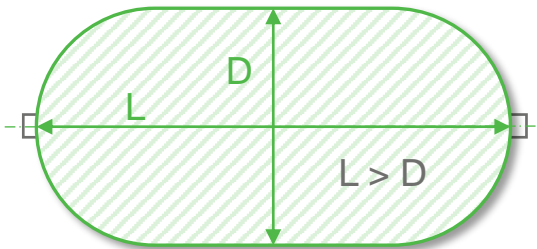
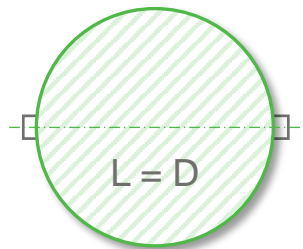
Weight:	- 15%
Cost:	- 10%
Process time:	- 15%

1) Savings potential depend on individual vessel characteristics

Opportunity sizing: Tank aspect ratio drives savings potential

The tank aspect ratio drives the potential for material savings. The longer the vessel in relation to its diameter, the higher the improvement potential.

Tank geometries with different aspect ratios



Saving potential by using dome reinforcements

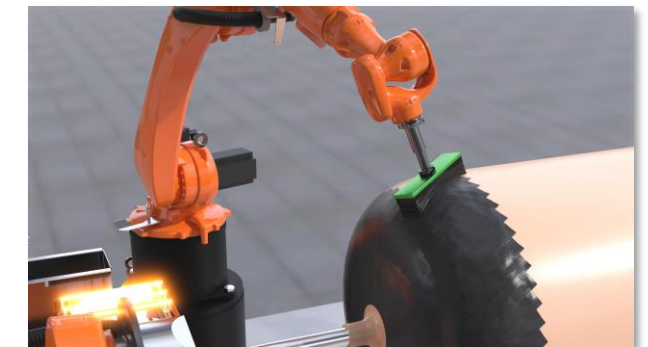
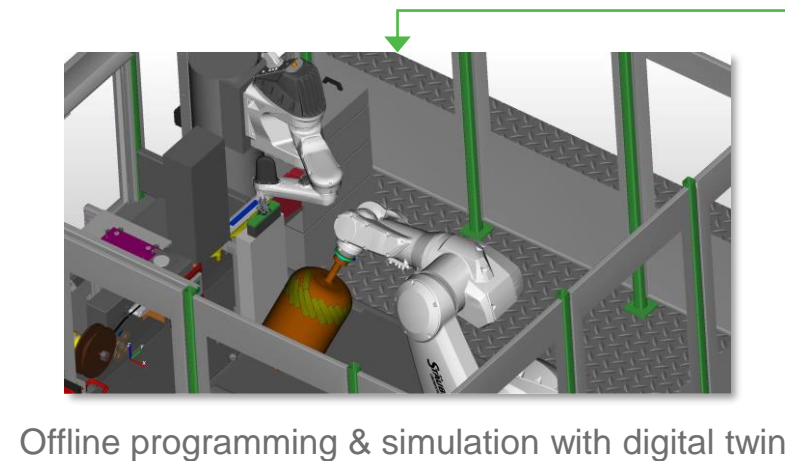
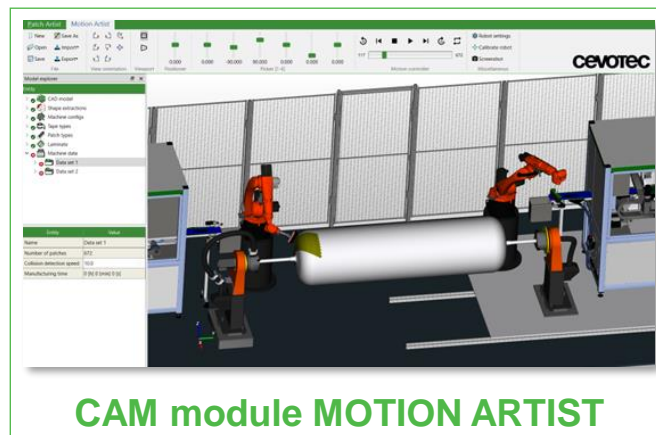
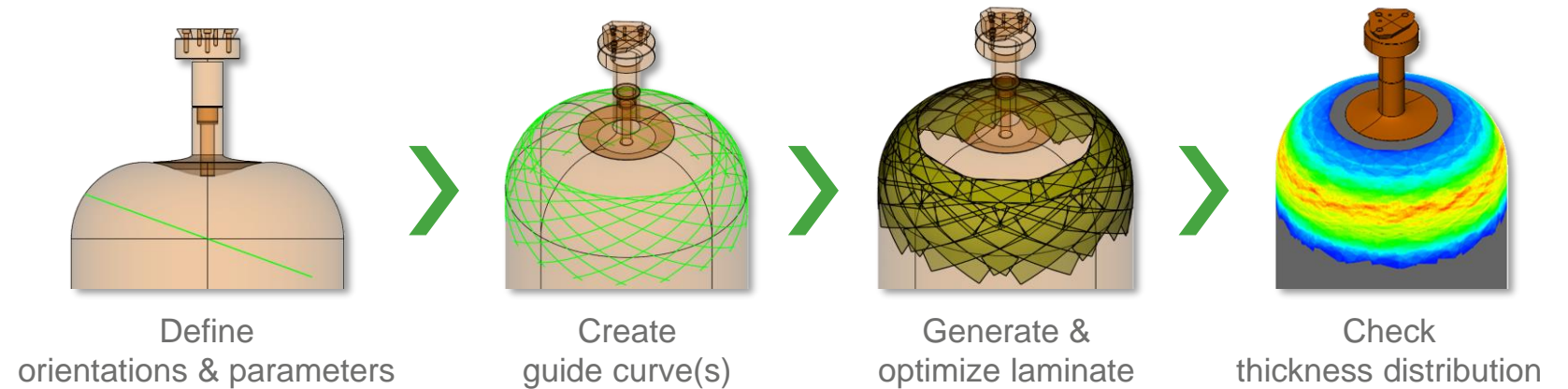
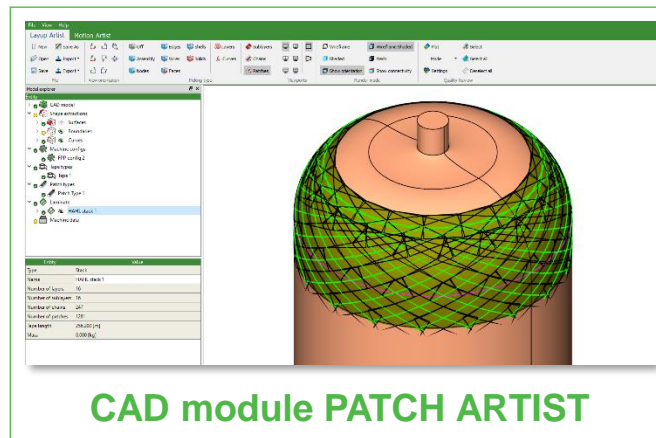
$L / D = 1$ → No saving potential

$L / D > 1$ → Saving potential growing

$L / D > 5$ → Large saving potential

Product development: Dome reinforcements with Fiber Patch Placement

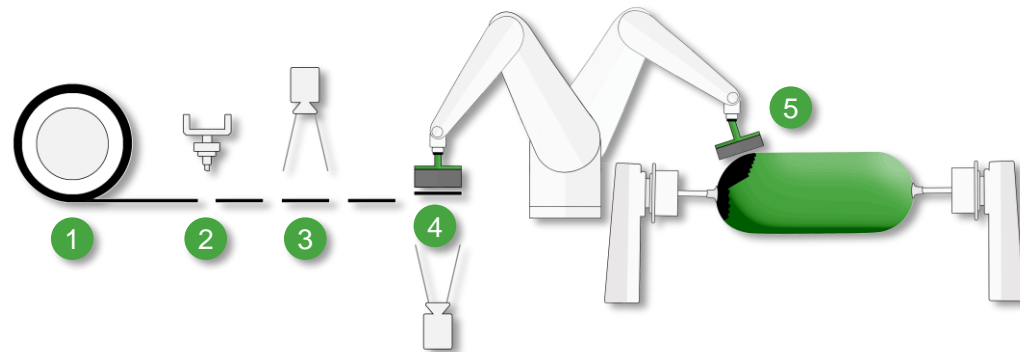
FPF software ARTIST STUDIO creates patches automatically along defined guide curves and performs automated robot offline-programming. Dedicated design features for dome reinforcements available.



The Fiber Patch Placement process for dome reinforcements

3D dome reinforcement lay-up is performed directly on the liner in the proven, sensor-controlled FPP process that features a comprehensive quality protocol of every patch placed.

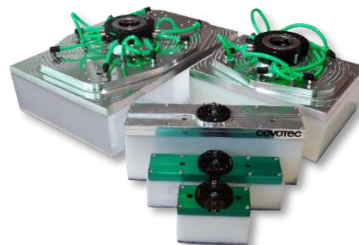
Process overview



- 1 | Feed fiber tape
- 2 | Cut tape into patches
- 3 | Inspect quality
- 4 | Pick-up, check position
- 5 | Place reinforcement patch on dome

Dedicated gripper technology

- Controlled fiber deposition on convex surfaces
- Placement directly onto the liner
- Various size; customized to vessel geometry



Demonstrator production on lab system SAMBA Pro



[Watch the full demo video on YouTube](#)

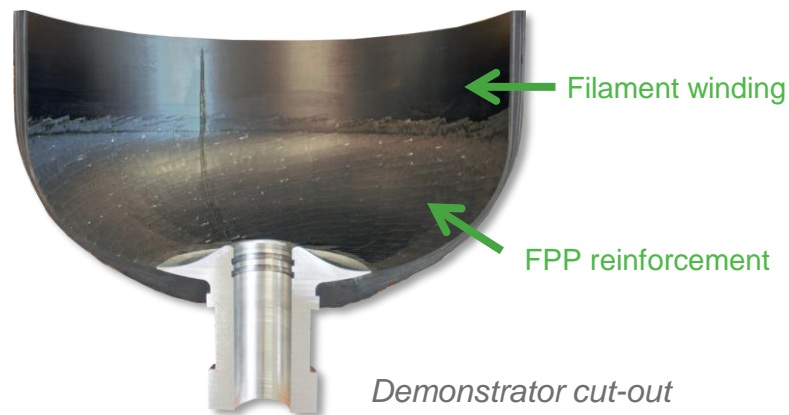
FPP dome reinforcements evaluated with industry partners

Developing an optimized small composite tank with partners Roth & CIKONI demonstrated the capabilities of Fiber Patch Placement for dome reinforcement on a series vessel.

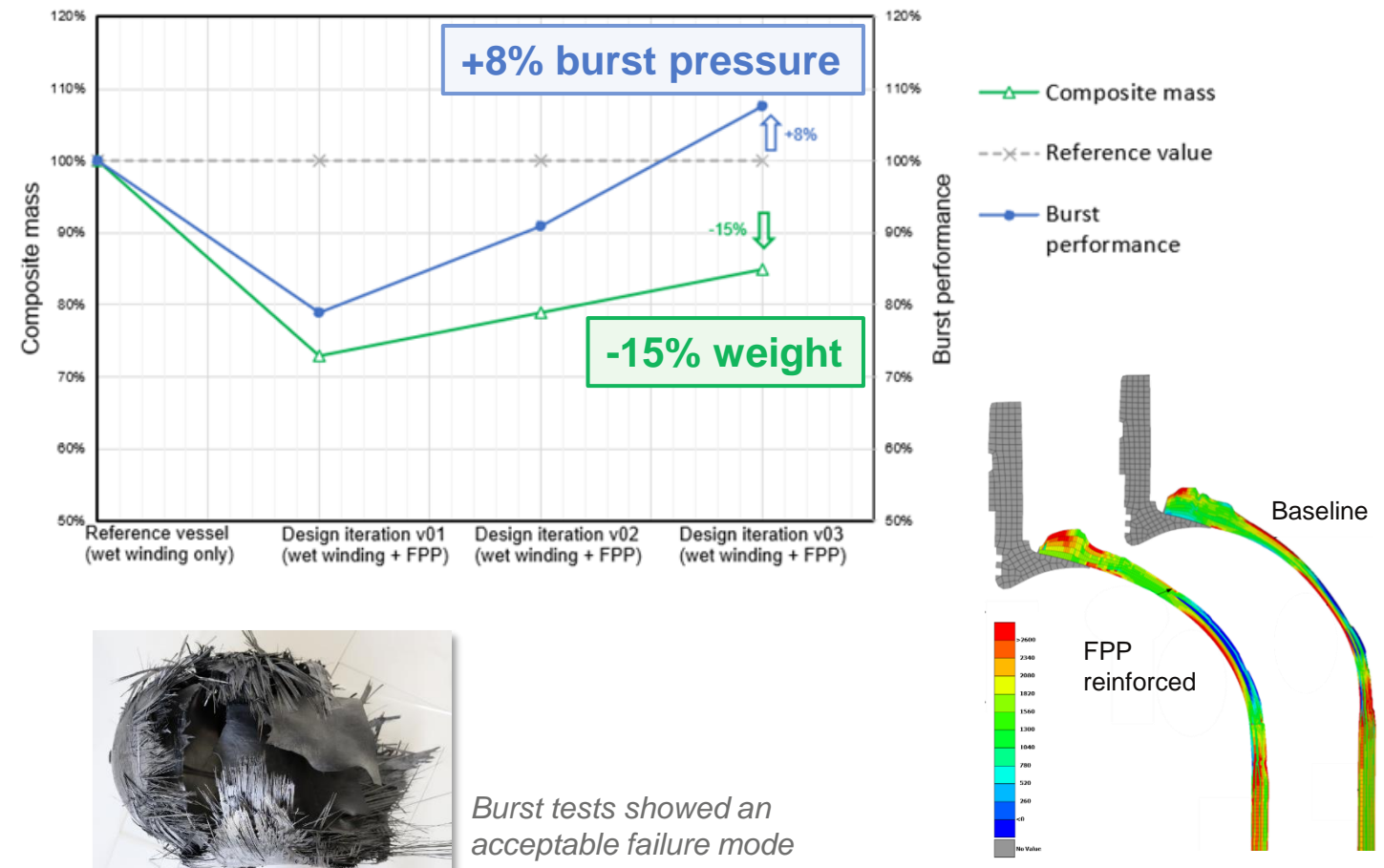


Project outline & goals

- Optimization of fiber lay-up, also by simulation, of the dome reinforcement and the winding laminate
- Reduce weight, production time and cost
- Ensuring required mechanical performance by burst pressure tests according to industry norms
- Project successfully completed in Q3 / 2023



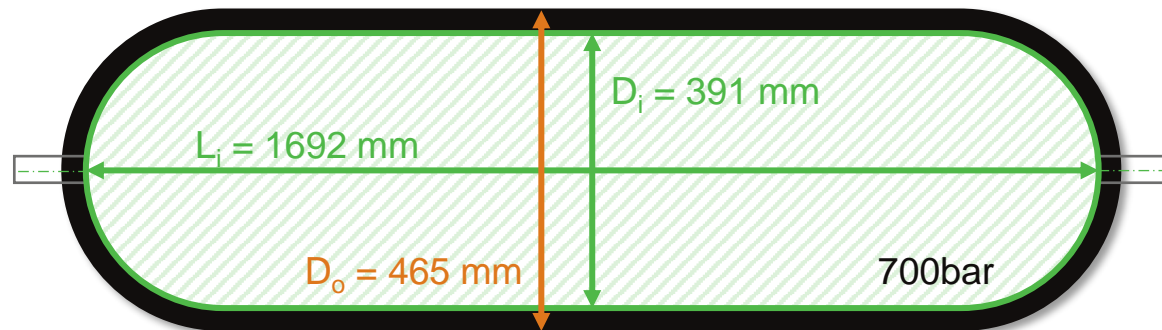
Project results



Boosting storage efficiency by reduced weight & increased volume (example)

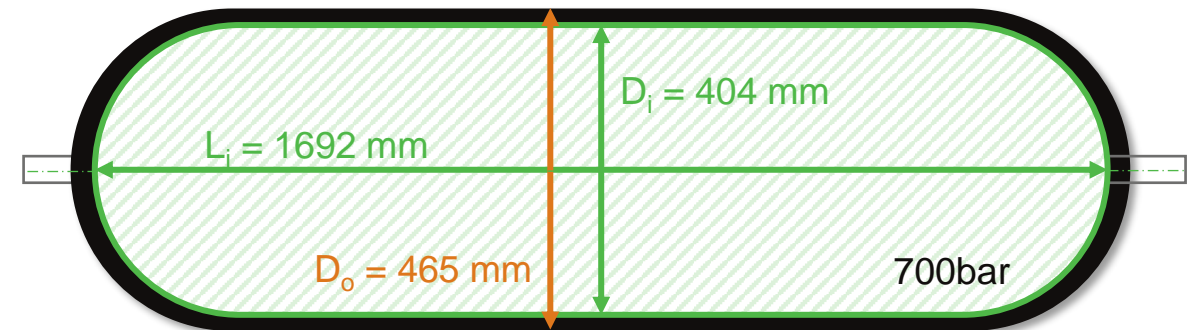
In this example, the reinforced vessel yields a 13% material reduction combined with a potential 7% storage volume increase at same outer diameter, boosting storage efficiency by 19% to 6.5%.

Case study reference vessel (illustrative)



- $V \approx 180 \text{ l}$
- Mass CF composite $m_{CF} \approx 116.2 \text{ kg}$
- H2 mass storage $m_{H2} \approx 7.54 \text{ kg}$ (@ 700 bar | 40 kg/m^3)
- Storage efficiency $m_{H2} / (m_{CF} + m_O + m_{H2}) \approx 5.5\%$

Dome-reinforced vessel (illustrative)



- Volume, $V \approx 192 \text{ l}$
- **-13%** → · Mass CF composite $m_{CF} \approx 101.2 \text{ kg}$
- **+7%** → · H2 mass storage $m_{H2} \approx 8.05 \text{ kg}$ (@ 700 bar | 40 kg/m^3)
- **+19%** → · Storage efficiency $m_{H2} / (m_{CF} + m_O + m_{H2}) \approx 6.5\%$

Three areas of economic benefit for composite tank OEM

Dome reinforcements for pressure vessel generate economic benefits in three areas: material, takt time and line capacity, and product performance. Manufacturers can exploit all of them simultaneously.



Lower material cost

Approx. 15%¹ less material used for equivalent mechanical performance, net of reinforcement cost.

→ **Material cost savings**



Faster takt time

Patching and winding happen in parallel in series production. That reduces takt time by up to 20%¹.

→ **More output by line and plant**



Better product

Reinforced tanks weigh 15%¹ less and can feature up to 10%¹ more storage volume.




→ **Pricing opportunity for first movers**

Note: 1) Savings depend on specific vessel design and production set-up; contact us to receive an individual evaluation on your vessel design

The business case for FPP dome reinforcements (illustrative example)

Material cost savings drive the business case, improving unit economics by 15% - 20%. Payback on investment in 10-20 months, depending on material system.

Business case: per-unit economics

		Towpreg winding	Wet winding
Delta material cost		450,60 €	216,10 €
Delta FPP production cost		-45,99 €	-45,99 €
Net benefit replacing HABL with FPP		404,61 €	170,11 €
Delta process time		-11%	-14%
Resulting delta in equipment cost FW		1,82 €	6,61 €
Net benefit from faster cycle time		1,82 €	6,61 €
Assumed sales price		7.500 €	7.500 €
Price increase opportunity		2,5%	2,5%
Price / margin opportunity for 5 years		187,50 €	187,50 €
Total benefit per unit		593,93 €	364,22 €
as percentage to baseline cost (for composite shell)		14%	18%
Profit margin opportunity (based on sales price)		7,9%	4,9%

Key assumptions: material: TP 35€/kg, WW 17€/kg; avg. speed: TP 1.6m/s, WW 0.5m/s

Investment case: 10-yr production of 10.000 units p.a.

	Towpreg winding	Wet winding
Total CAPEX baseline (without reinforcements)	1.325.000 €	3.775.000 €
Total CAPEX incl. reinforcement equipment	5.940.000 €	8.015.000 €
Non-recurring development costs	250.000 €	250.000 €
One-off investment delta	-4.865.000 €	-4.490.000 €
Yearly benefits	5.939.325 €	3.642.158 €
Payback period (months)	10	15
Internal rate of return (IRR)	121%	79%
Net present value (NPV)	31.769 €	16.527 €

Key assumptions: 8% discount rate, one-off investment cost considers all delta costs to set-up 10k p.a. production

► 15% cost improvement / benefits per tank

► Investment pays back in < 2years

Contact us to request a sample calculation for your specific vessel and production setting!

SAMBA Pro PV-1: FFP lay-up system dedicated to composite tank reinforcements

System lay-up optimized for industrial production of dome reinforcements directly on vessel liner.
Compatible for a broad range of vessel geometries and material systems.

SAMBA Pro PV-1

- 2x robots units for parallel patching of both domes
- Compatible with many fibers
- Sensor-controlled process
- Liner length: up to 3,500mm
- Diameter: up to 1,000 mm
- **Available for projects from Q2 2024 onwards**



 [Watch the full video on YouTube](#)



FFP composite tank dome reinforcements ...

- ▶ save weight & cost
- ▶ improve storage efficiency
- ▶ are placed fully automated, no post-processing
- ▶ are compatible with existing wet and towpreg winding
- ▶ **improve the sustainability of composite tanks by significantly saving on CF material**

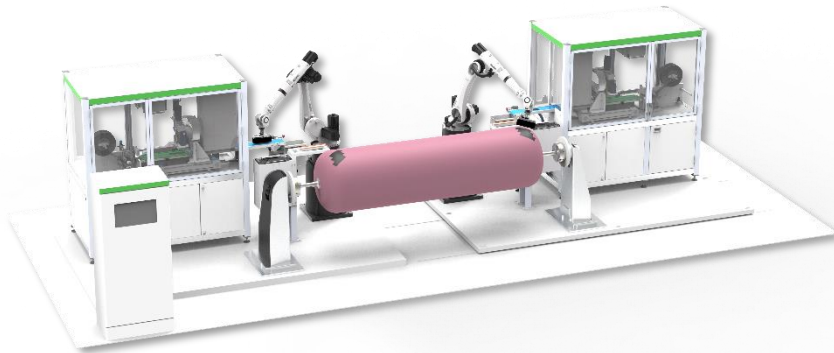


The Cevotec portfolio

Specialized automation equipment, software and services based on Fiber Patch Placement.
We support from initial concept to series production and beyond.

SAMBA Series

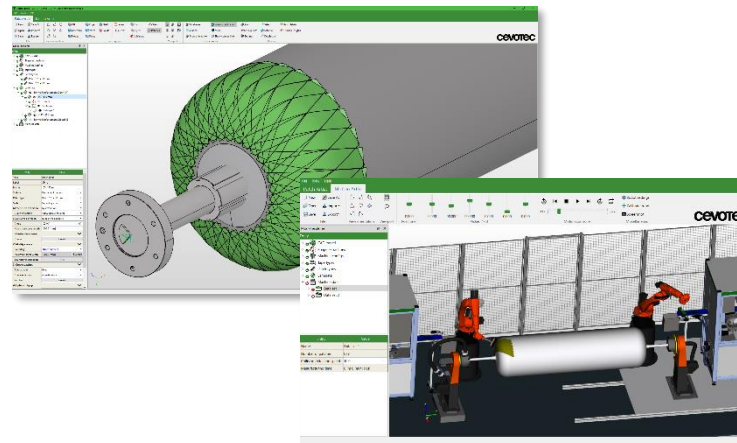
FPP automation platform



- FPP lay-up system dedicated to dome reinforcements
- Sensor-controlled & documented process
- Maintenance service & engineering support

ARTIST STUDIO

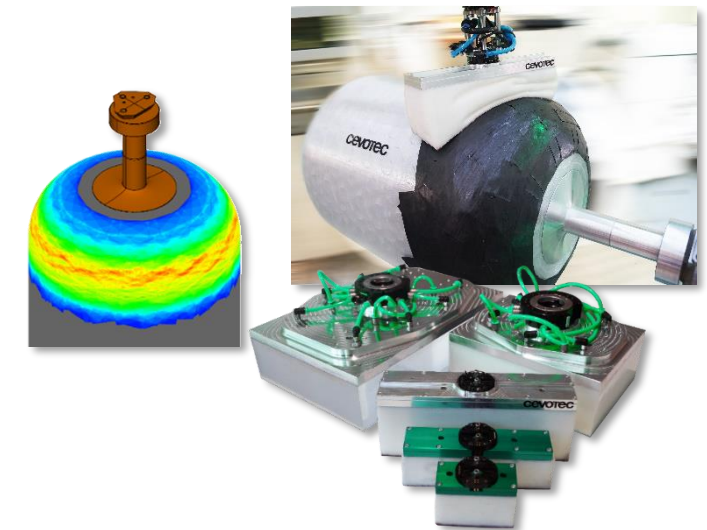
CAE software platform



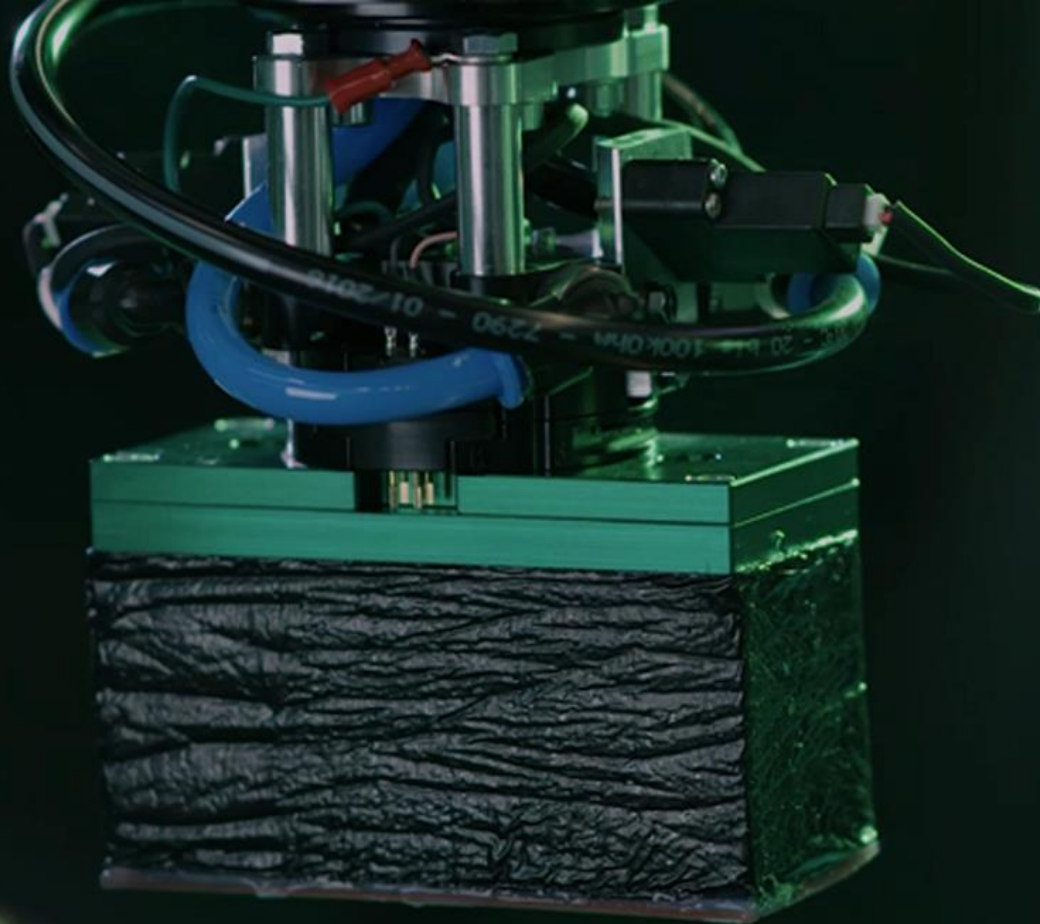
- CAD-CAM for patch technology
- Automated programming of SAMBA systems
- Interface module for FE software available
- Dedicated design features for composite tanks
- Training and consulting for engineering teams

cevoLab

FPP Competence Center



- Application & process development
- Customization of equipment
- Prototyping & low-volume production
- CAE analysis & FEM-based optimization



cevotec
milestones in composites

How to get started with Fiber Patch Placement?

Step 1: ROI & suitability assessment

Includes manufacturability assessment, unit cost & time analysis, benefits & ROI estimation. This service is free of charge.

→ **How much does your application benefit from FPP?**

Step 2: Joint application development

Includes virtual studies, application and demonstrator development, equipment customization, and more.

→ **How do you best develop & test your FPP application?**

Step 3: Customized lay-up equipment

Includes SAMBA lay-up systems, ARTIST STUDIO software, customized patch grippers, quality control systems, and more.

→ **Which system configuration is best for your application?**

Get started with

Fiber Patch Placement

☎ +49 89 2314 1650 ✉ advantages@cevotec.com 🌐 www.cevotec.com

We enable manufacturers to produce complex composites in high volume and superior quality.
For a lighter, more sustainable future.

cevotec
milestones in composites

Cevotec GmbH
Biberger Str. 93
82008 Unterhaching
Phone +49 89 2314 165 0
Fax +49 89 2314 165 99
info@cevotec.com
www.cevotec.com