Dome reinforcements for composite tanks

Automated production with Fiber Patch Placement yields improvements in weight, cost, cycle time and storage efficiency

October 2022

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milestones in composites

Hydrogen-powered mobility drives demand for pressure tanks

The use of hydrogen-powered, fuel cell electric vehicles (FCEV) is growing fast. This drives significantly the demand for composite pressure vessels in the upcoming decades.

Hydrogen storage: pressure vessels

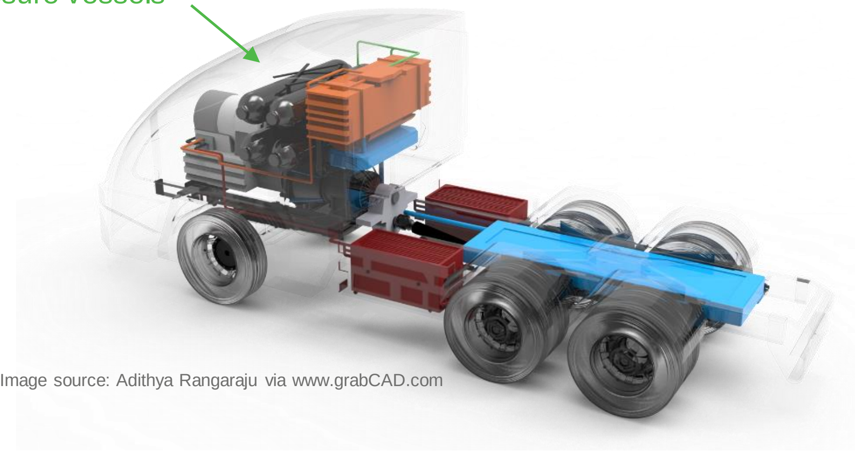
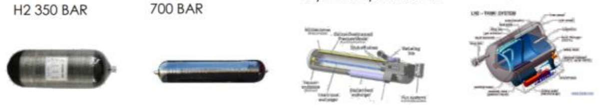


Image source: Adithya Rangaraju via www.grabCAD.com



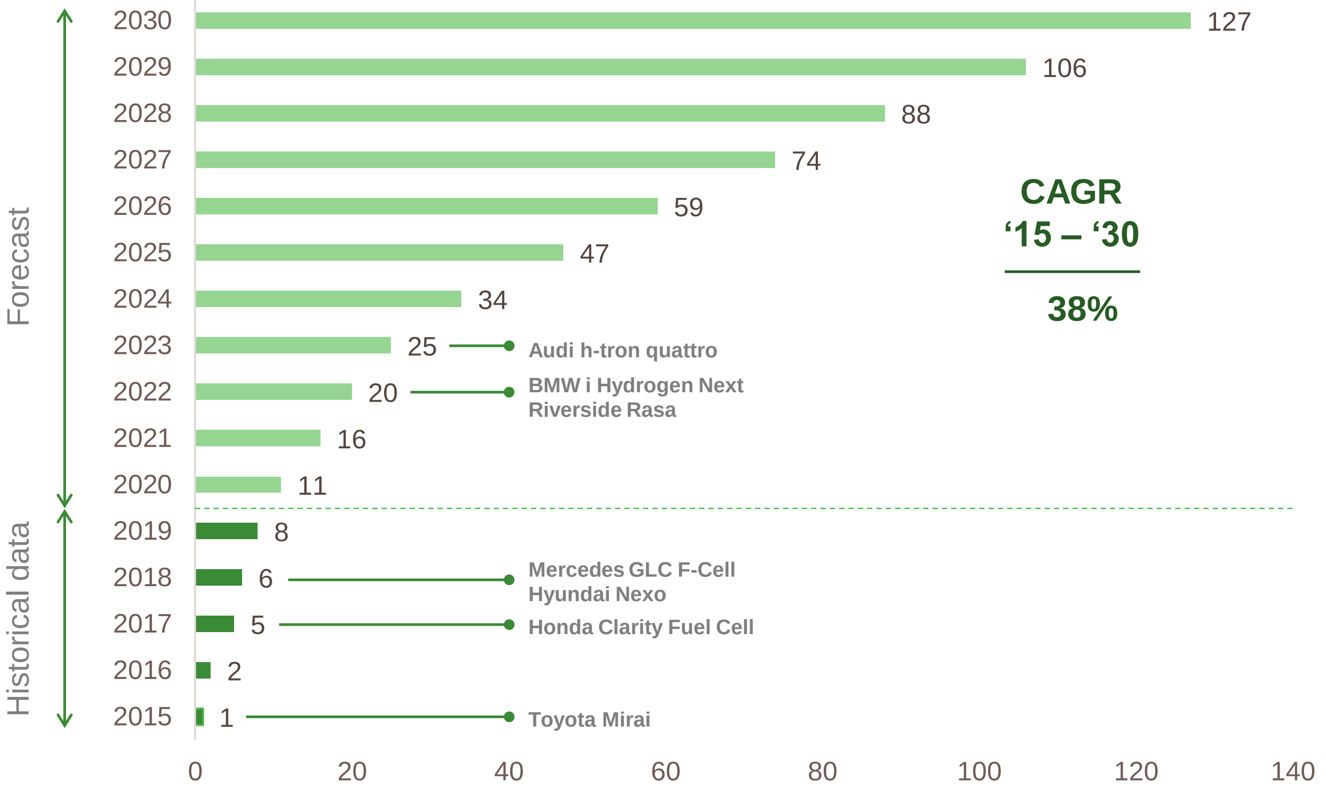
Hydrogen Storage

Available options

	Compressed H2 350 BAR	Compressed H2 700 BAR	Cryo Compressed H2	Liquid H2
Max storage pressure	350 bar	700 bar	300 bar	4 to 6
Volumetric Density (including BoPs)*	16 g H2/L of Tank	27 g H2/L of Tank	40 g H2/L of Tank	36 g H2/L of Tank
Maturity (status Aug 2020)*	Very Mature	Very Mature	Prototype	Mature for other applications (Aerospace)

Source: CNHi Study, Turin 2020

Global annual hydrogen vehicle production (k units)

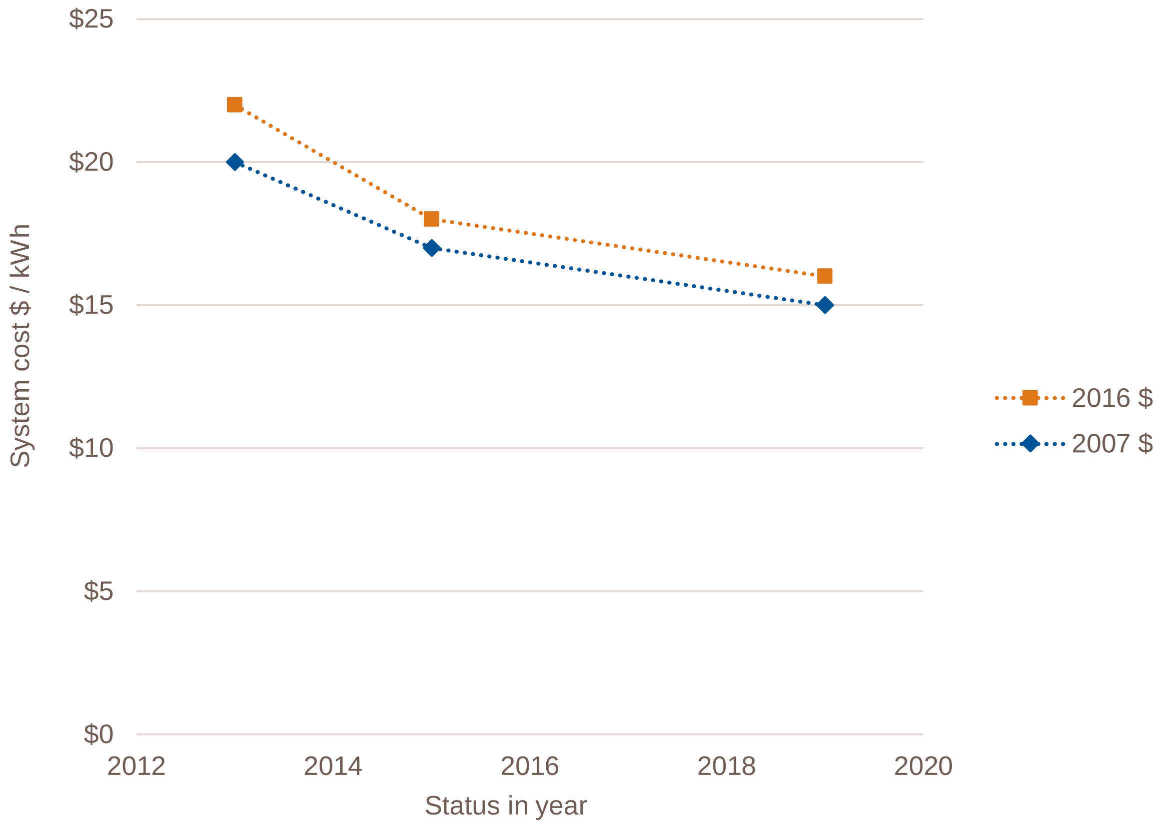


Source: adapted on the basis of JEC Observer, March 2022, based on HIS Markit, Statista, press releases, Estin & Co analyses and estimates.

System cost for hydrogen-based stored energy

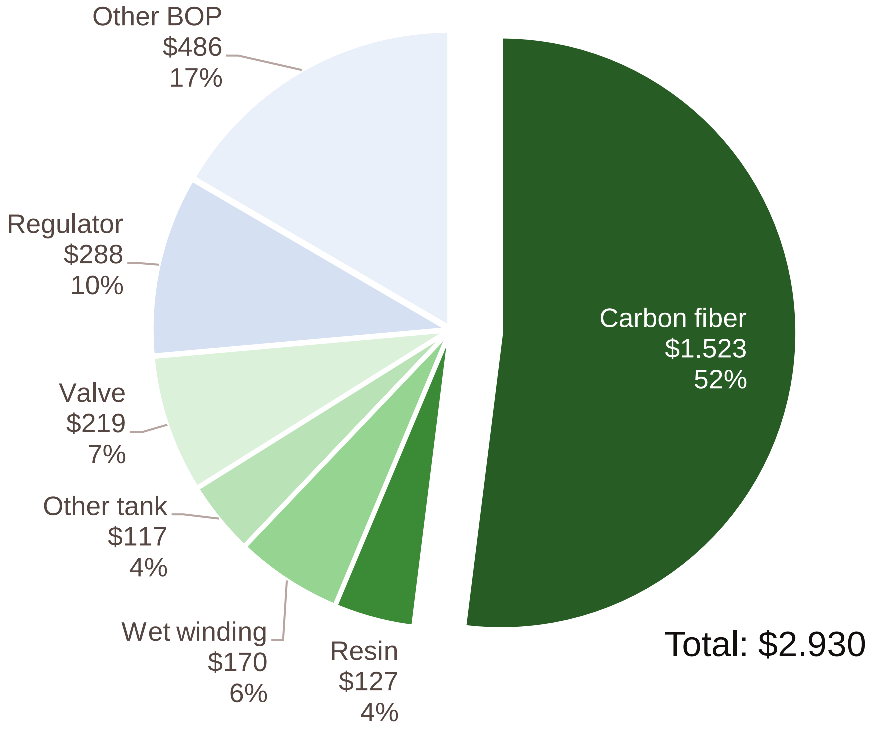
While storage system cost have decreased notably in the last decade, carbon fiber material is still the largest cost reduction opportunity, presenting over 50% of total cost of storage system.

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)

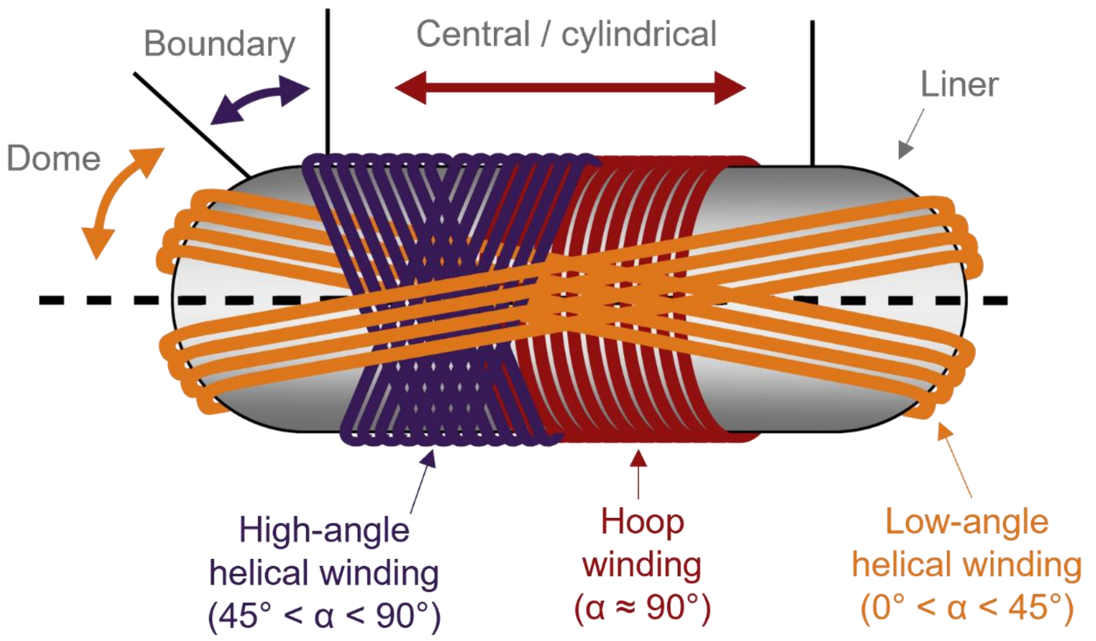


Source: based on J. Adams, et al.; Department of Energy, USA; DOE Hydrogen and Fuel Cells Program Record, 2019

Fiber angle impact on performance

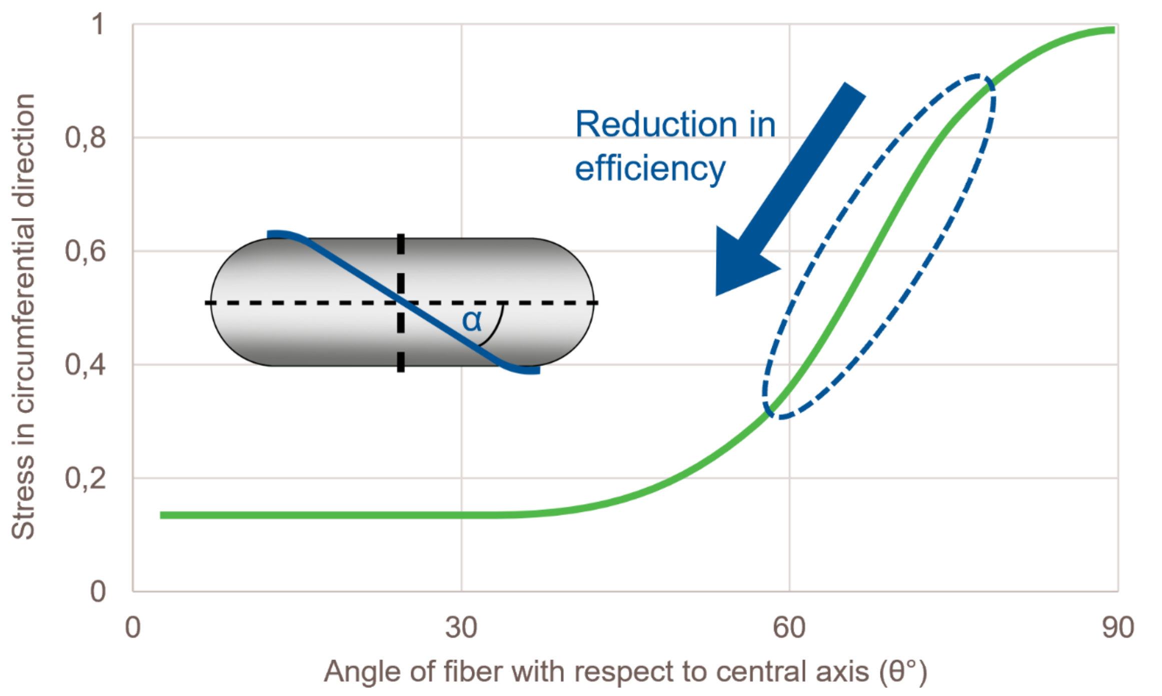
Analysis of winding laminates of pressure vessels shows that high-angle helical layers contribute mostly to the dome section and could be omitted in the cylindrical section.

3 types of winding patterns in pressure vessels



Source: based on A. Fuchs; Toyota Motors Europe; Herausforderungen bei der Massenproduktion von Brennstoffzellenfahrzeugen, 2016

Circumferential stress in relation to fiber angle (to central axis)

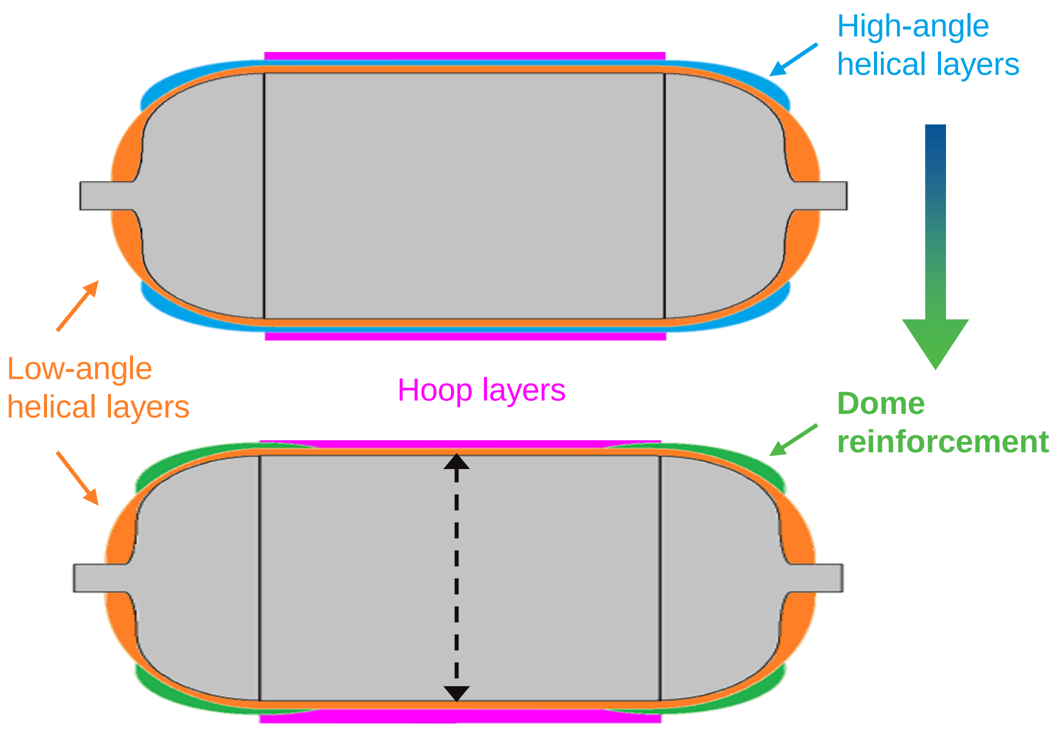


Source: based on A. Fuchs; Toyota Motors Europe; Herausforderungen bei der Massenproduktion von Brennstoffzellenfahrzeugen, 2016

Dome reinforcements for pressure vessels yield 15% material efficiency

Replacing high-angle helical layers by dome reinforcements in the dome sections results in 15% less material required to achieve similar mechanical vessel properties.

Replacing high-angle helical layers with reinforcements



Potential volume increase
given fixed outer diameter / built space

Opportunity to reduce 15% of carbon fiber material

"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. […] **As a result**, the **stress distribution across the thickness of the composite is more uniform**, and the **total amount of carbon fiber composite needed is reduced**."

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.

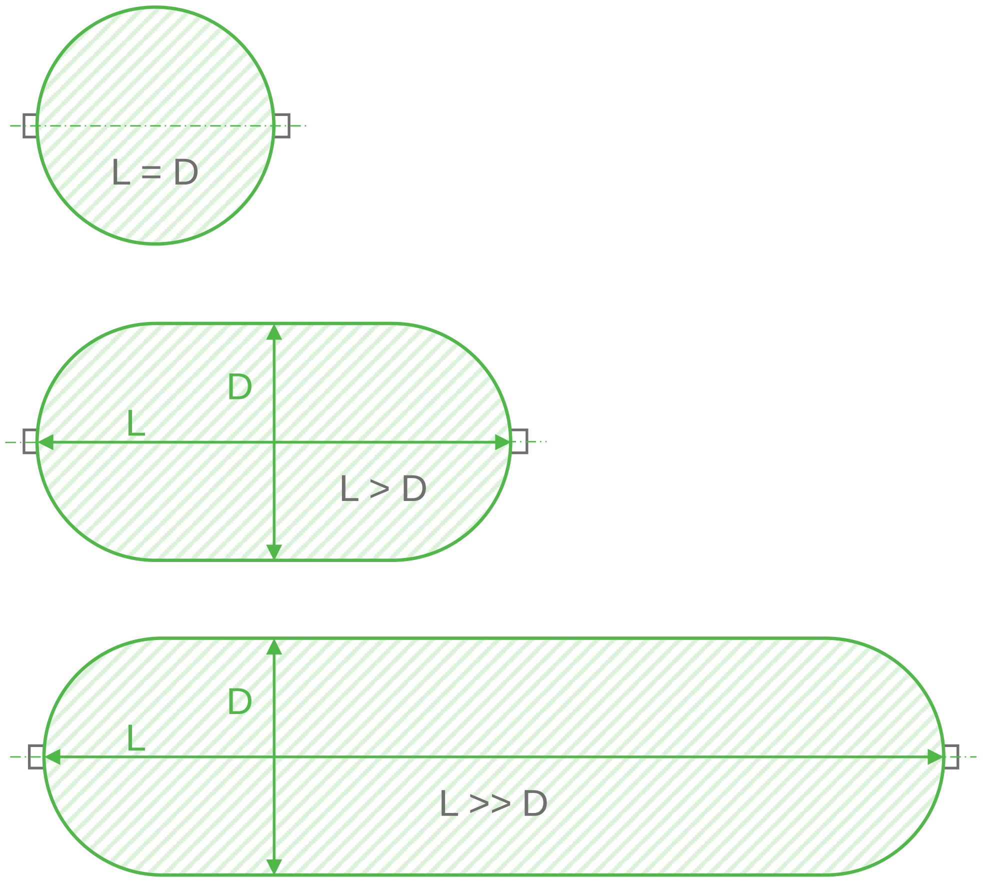
		Weight (kg)			
	Doilies	Hoop	Helical	Doilies	Total
2013 Baseline [2]	Yes	40.2	48.0	2.8	91.0
Calibrated Performance Model	No	34.3	72.3	N/A	106.6

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

Opportunity sizing: general assessment of dome reinforcement potential

The tank aspect ratio drives the potential for material savings and volume increases on available built space. The longer the vessel in relation to its diameter, the higher the improvement potential.

General geometries of tanks



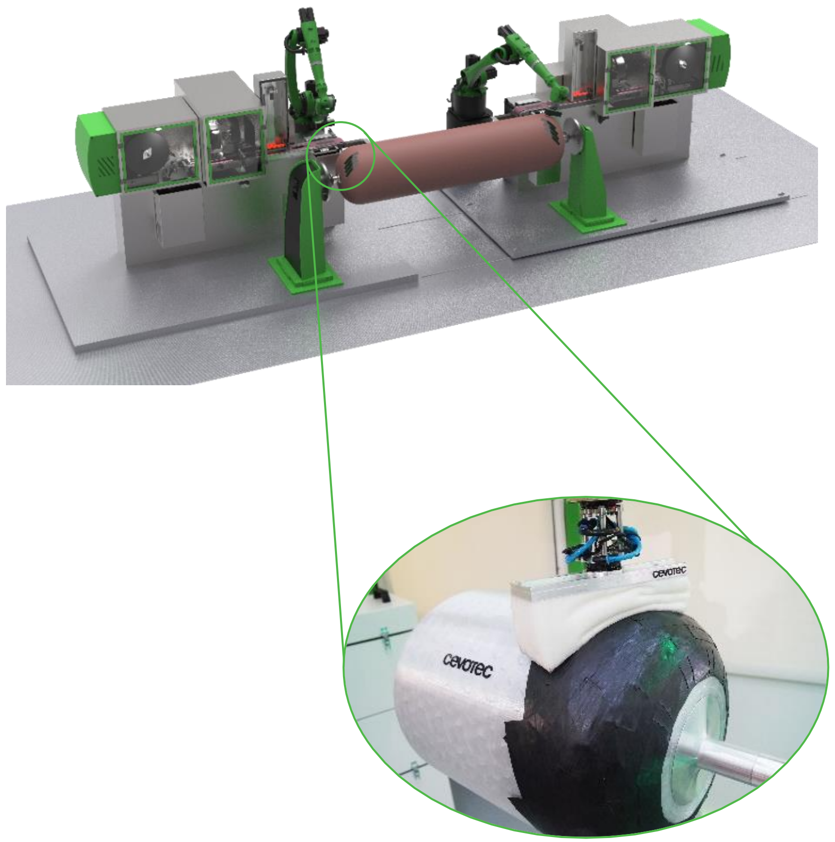
Saving potential for dome reinforcement

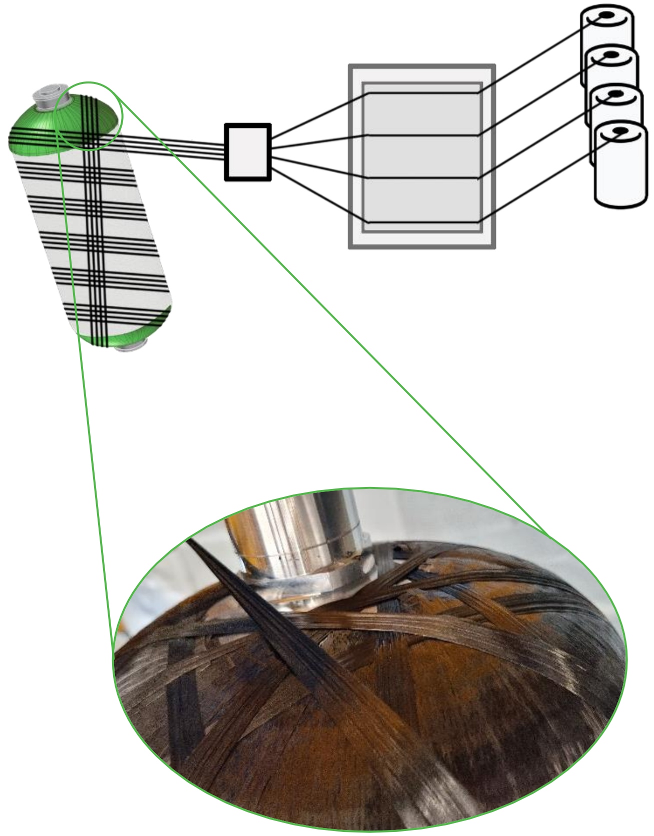
L / D = 1	→ No saving potential
L / D > 1	→ Saving potential growing
L / D > 5	→ Large saving potential

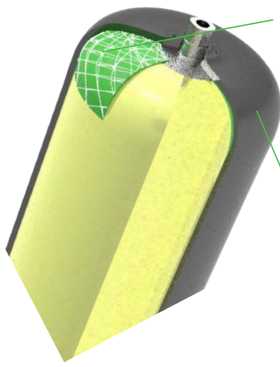
Solution for automated industrial production of reinforced tank domes

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

1 Automated liner reinforcement + **2 Filament winding (less material)** = **3 Lighter composite tank**





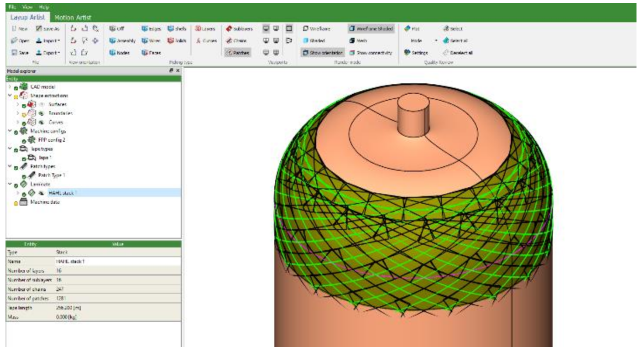


Savings per vessel[1]

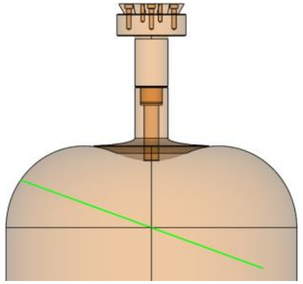
Weight:	**- 13%**
Cost:	**- 10%**
Process time:	**- 13%**

Development process: Dome reinforcements with Fiber Patch Placement

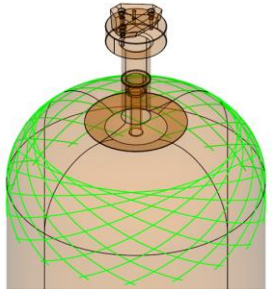
The CAD-CAM software ARTIST STUDIO creates patches automatically along user-defined guide curves. Robots offline-programming is fully automated based on digital twin of laminate & robot cell.



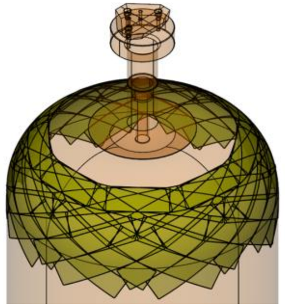
CAD module PATCH ARTIST



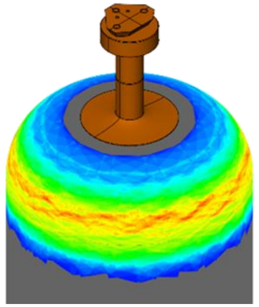
Define orientations & parameters



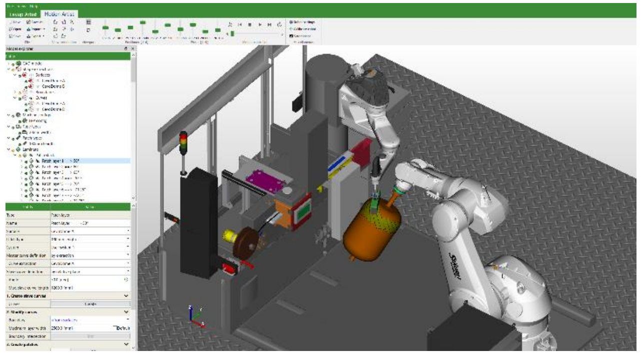
Create guide curve(s)



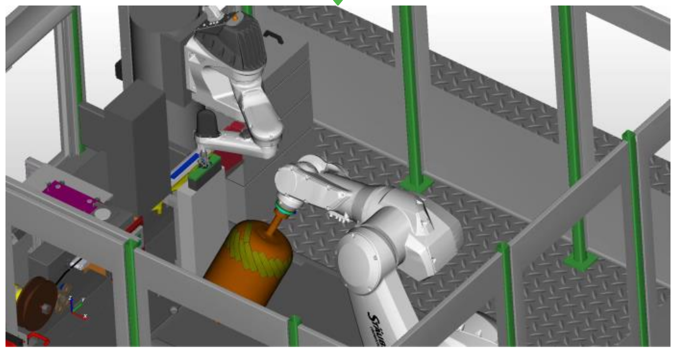
Generate & optimize laminate



Check thickness distribution



CAM module MOTION ARTIST



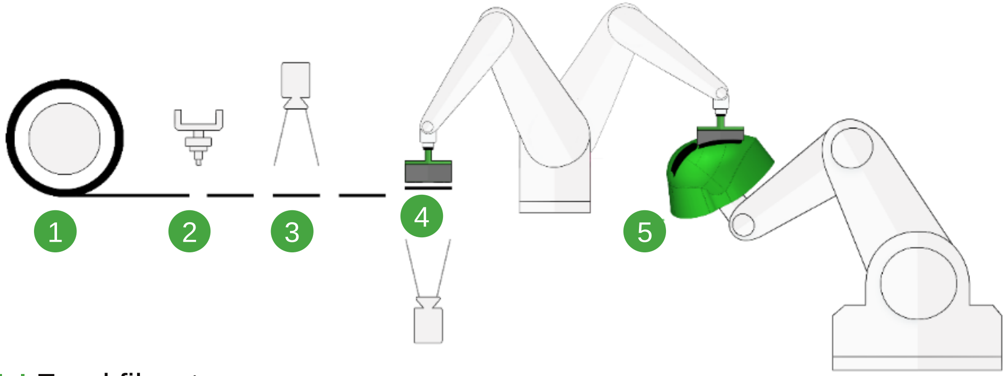
Offline programming & simulation with digital twin

Production on SAMBA *Pro* lab system

The Fiber Patch Placement process

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 I Feed fiber tape

2 I Cut tape into patches

3 I Inspect quality

4 I Pick-up, check position

5 I Place fiber patch

Dedicated gripper technology

- Controlled fiber deposition on convex surfaces
- Placement directly onto the liner
- Size customized and optimized to vessel geometry

Demonstrator production on lab system SAMBA Pro

Watch the full demo video on YouTube

Three areas of economic benefit increase the gross margin of production lines

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

Replacing HAHL with FPP

Approx. 15% less material used for equivalent mechanical performance, net of FPP production cost.

→ **Material cost savings**

Faster cycle time

Patching and winding happen in parallel. That reduces overall cycle time by up to 20%.

→ **More output / gross margin by line and plant**

Better product

Reinforced tanks weight ~15% less and have more storage volume at same built space.

→ **Pricing opportunity for first movers**

The business case for FPP dome reinforcements

Material cost savings drive the business case. Payback on investment in 10-20 months, depending on material system. Storage efficiency improvement opens further opportunities in growing market.

Business case: per-unit economics

	Towpreg winding	Wet winding
Delta material cost	424,71 €	150,17 €
Delta FPP production cost	-36,58 €	-36,58 €
Net benefit replacing HAHL with FPP	**388,12 €**	**113,59 €**
Delta process time	-16%	-18%
Resulting delta in equipment cost FW	2,33 €	5,33 €
Net benefit from faster cycle time	**2,33 €**	**5,33 €**
Assumed sales price	7.000 €	7.000 €
Price increase opportunity	1,5%	1,5%
Price / margin opportunity for 5 years	**105,00 €**	**105,00 €**
Total benefit per unit	**495,45 €**	**223,92 €**
Percentage of baseline production cost	**18,6%**	**16,9%**

Key assumptions: material: TP 35€/kg, WW 17€/kg; production cost: TP 2.657€, WW 1.328€; avg. speed: TP 1.6m/s, WW 0.5m/s

15% - 20% cost savings & economic benefits per composite tank

Investment case: 10-year production of 30.000 units / year

	Towpreg winding	Wet winding
Difference in machine CAPEX	-10.370.000 €	-9.645.000 €
Add. handling equipment and integration	-1.000.000 €	-1.000.000 €
Artist Studio software cost	-100.000 €	-100.000 €
Non-recurring development costs	-250.000 €	-250.000 €
One-off investment cost	**-11.720.000 €**	**-10.995.000 €**
Yearly benefits	**14.863.607 €**	**6.717.509 €**
Payback period (months)	**10**	**20**
Internal rate of return (IRR)	126%	58%
Net present value (NPV)	85.005	30.688

Key assumptions: 8% discount rate, one-off investment cost considers all delta costs to set-up 30k p.a. production

10 – 20 months payback period of investment in series production setting

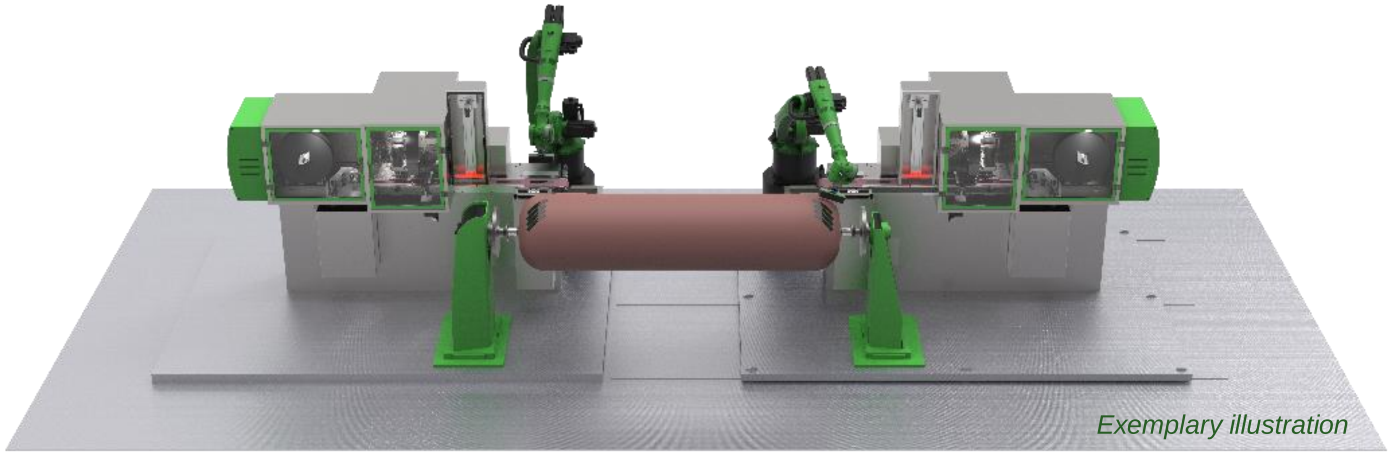
Please contact us for more details on the calculation or to request a sample calculation for your production setting.

SAMBA production system – optimized for pressure vessel reinforcements

System layout dedicated to industrial production of dome reinforcements directly on vessel liner.
One system fits a broad range of vessel lengths and diameters.

SAMBA *Pro PV-1*

- 2x robots and feeding units
- Simultaneous patching of both domes
- Linear rail for length variation
- Sensor-controlled process
- Compatible with a variety of fibers
- Automated robot offline programming
- Dedicated features for optimized lay-up planning



Exemplary illustration

Manufacturing trials / demonstrator projects on lab system available

Demo project: Full scale demonstrator of a reinforced pressure vessel

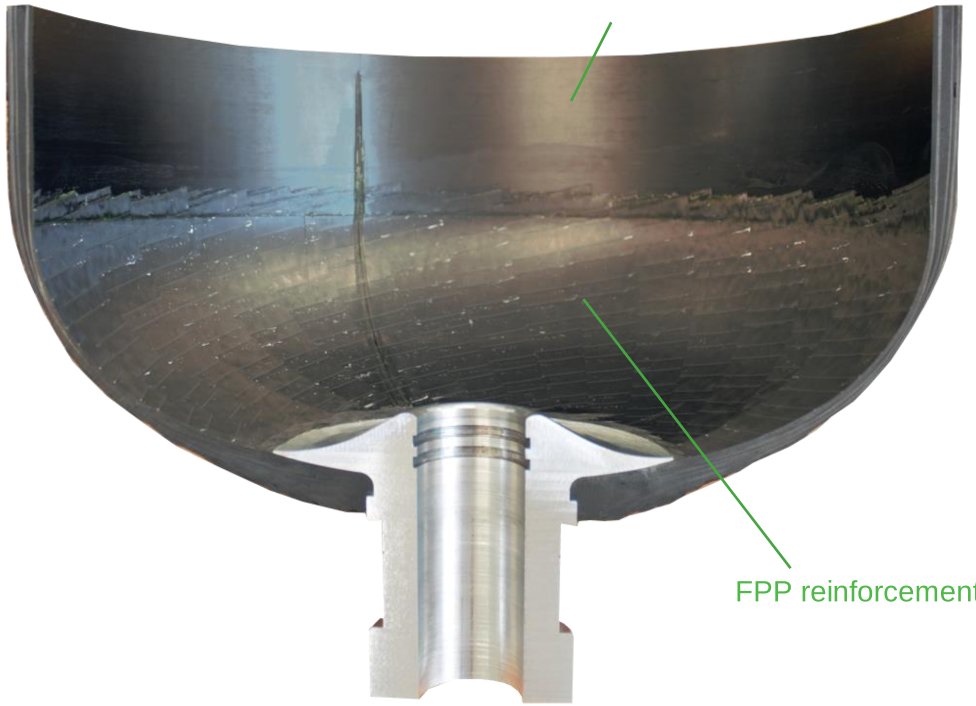
Developing an optimized full-scale demonstrator in a joint project with industry partners.

Project outline & goals

- Optimization of fiber lay-up, also by simulation, of the reinforcement laminate and winding laminate
- Minimizing cycle time and cost
- Ensuring required mechanical properties through comprehensive testing according to industry norms
- First results expected towards the end of 2022

Evaluation of impact of FPP dome reinforcements in industrial production setting

Cut-out of first trial lay-up



Summary: Storage efficiency improvement with Fiber Patch Placement

Dome reinforcements with the quality-controlled FPP process yield benefits in cost, weight and storage efficiency. Production systems are flexible in size and easy to integrate into industrial workflows.

FPP dome reinforcements ….

→ save weight & cost

→ improve storage efficiency

→ are placed fully automated

→ do not need any post-processing

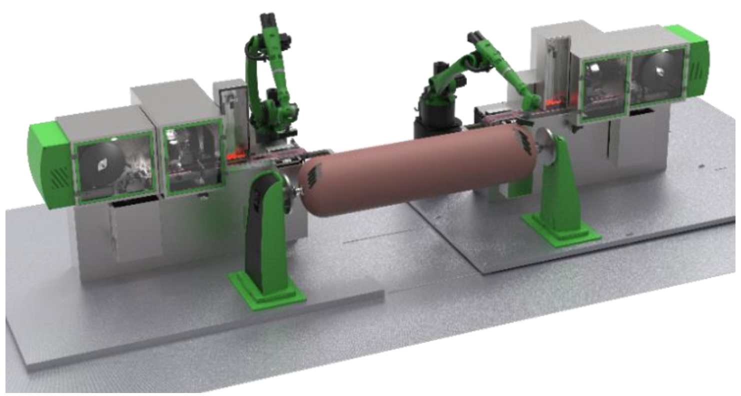
→ can be used with wet and towpreg winding

The Cevotec portfolio

Cevotec is an expert in patch-based production equipment & software for automation solutions. We support you from initial application development to series production and beyond.

SAMBA *Series*

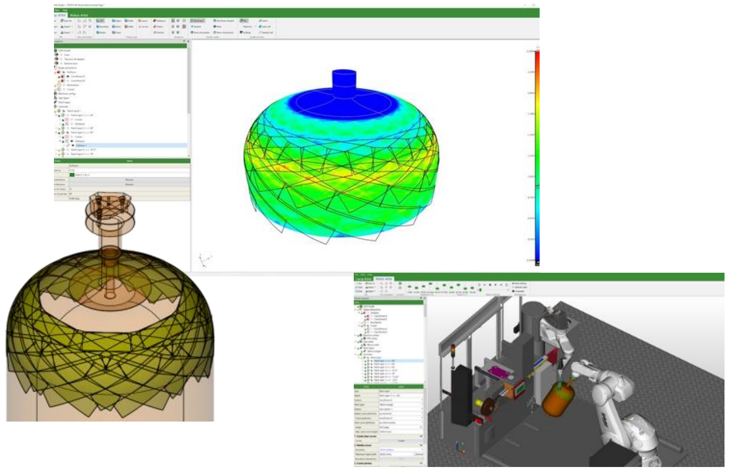
FPP automation platform



- Flexible 3D fiber lay-up platforms
- Configuration tailored 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

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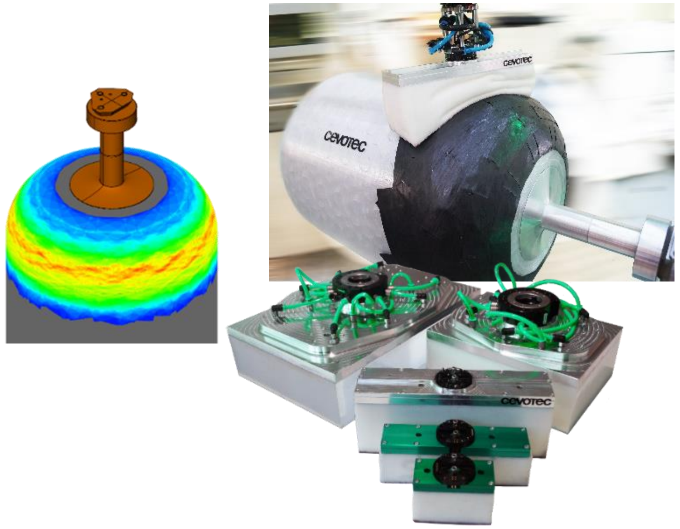
FPP Competence Center



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

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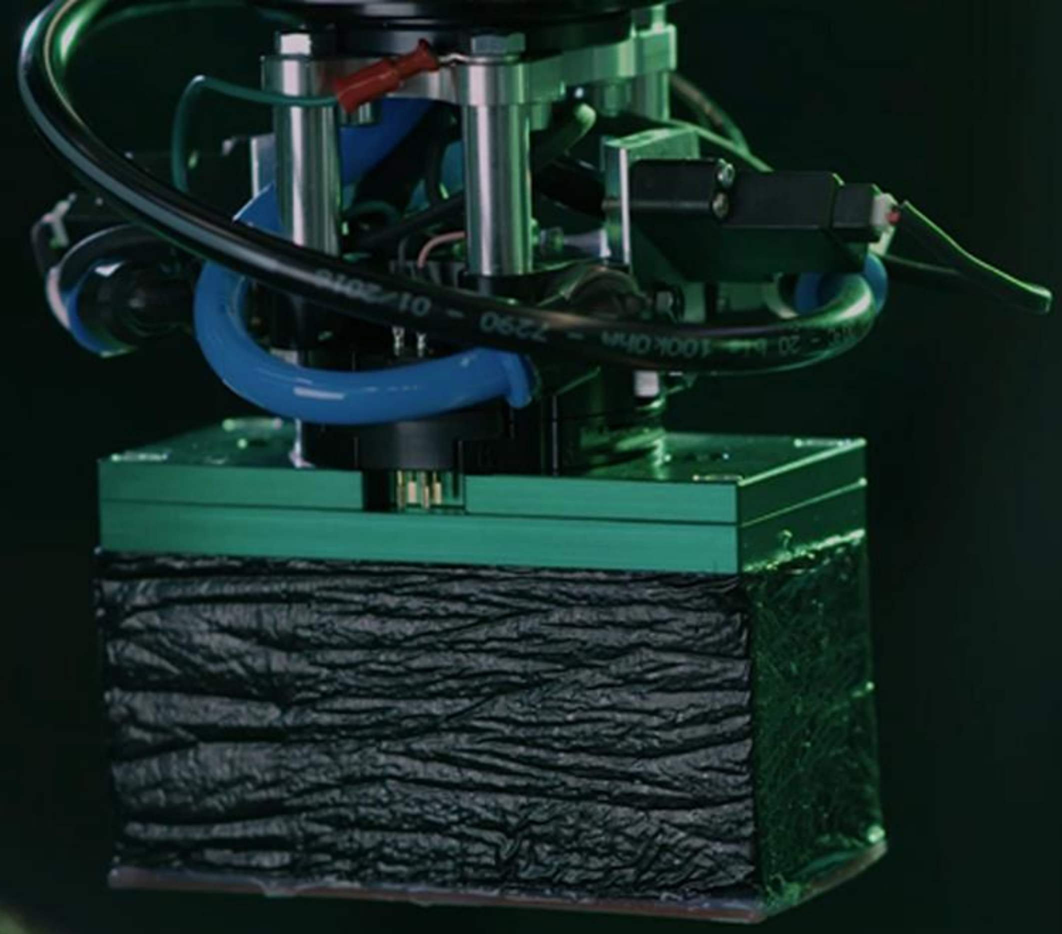

How to get started with Fiber Patch Placement?

Step 1: ROI & suitability assessment

Includes manufacturability assessment, unit cost & time analysis, benefits & ROI estimation. This service is complimentary for you.

→ **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.

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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