Dome reinforcements for composite tanks

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

May 2023

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milestones in composites

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

Hydrogen-powered vehicles are growing fast. This drives exponential demand for composite pressure vessels in the upcoming decades, creating significant growth pressure on the global CF market.

Hydrogen storage:
pressure vessels

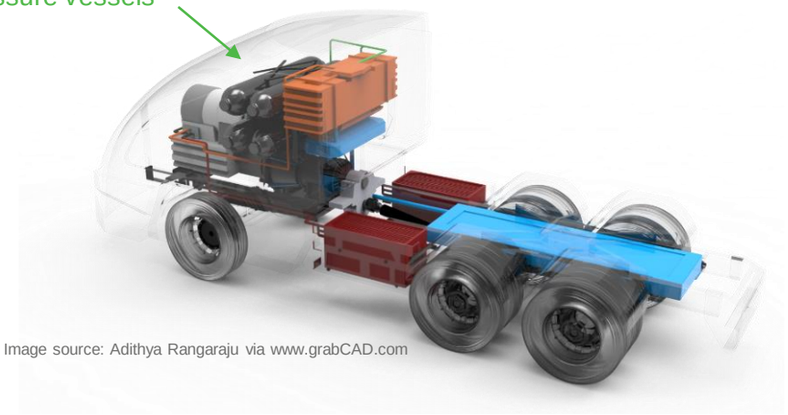
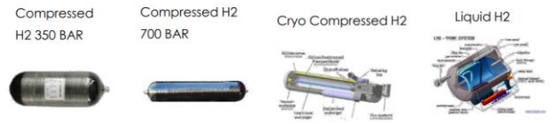


Image source: Adithya Rangaraju via www.grabCAD.com

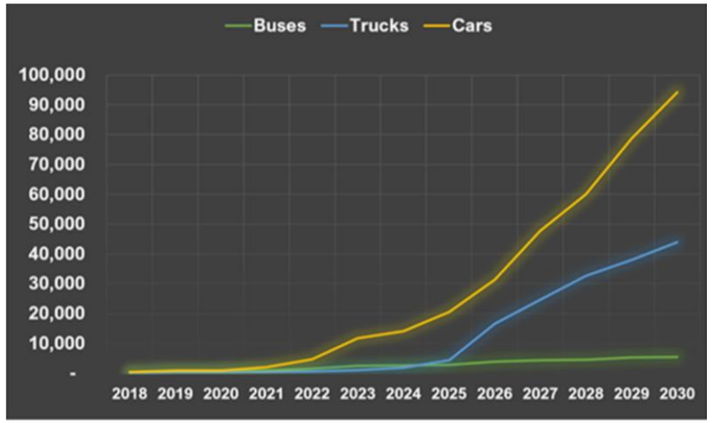
Hydrogen Storage

Available options



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



	2030 FCEV Projection	2020 Vechicle 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

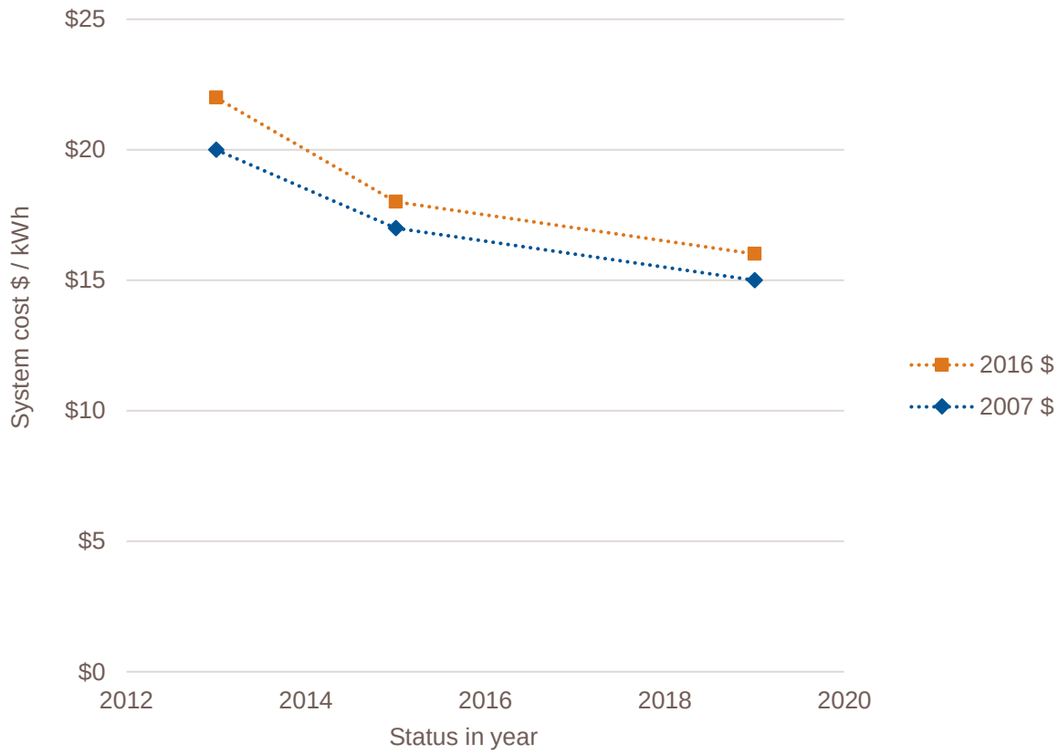
Compare with total global CF market today: approx. 100kt

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

System cost for hydrogen-based stored energy

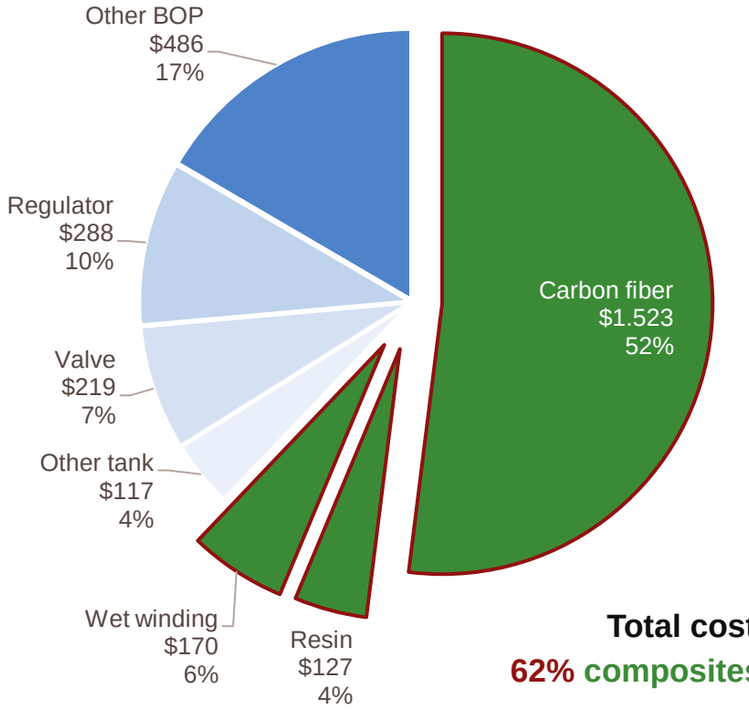
While storage system cost have decreased notably in the last decade, the composite shell is still the largest cost reduction opportunity, presenting over 60% of total cost of storage system.

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)



Total cost: $2.930

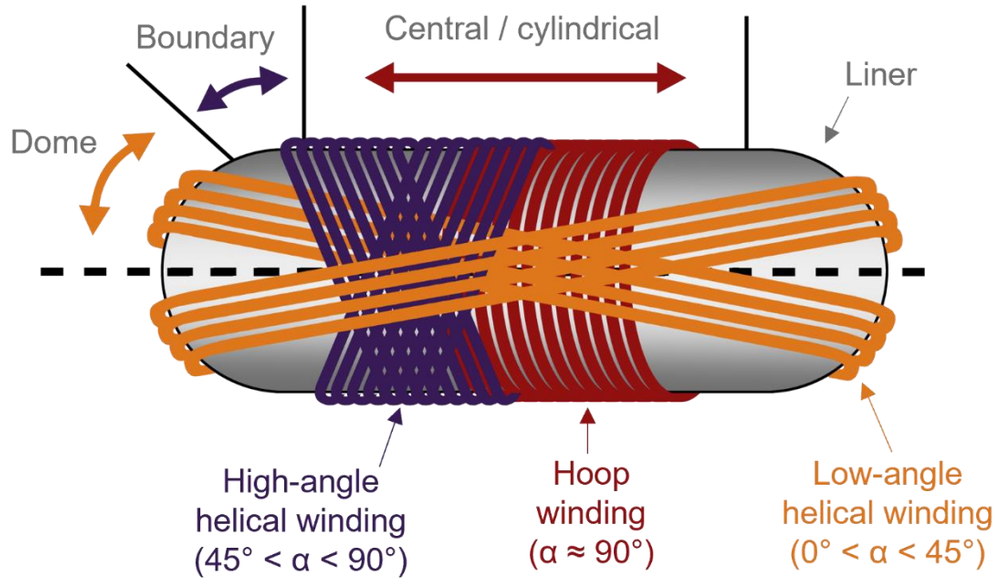
62% composites: $1.817

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

Fiber angle impact on performance

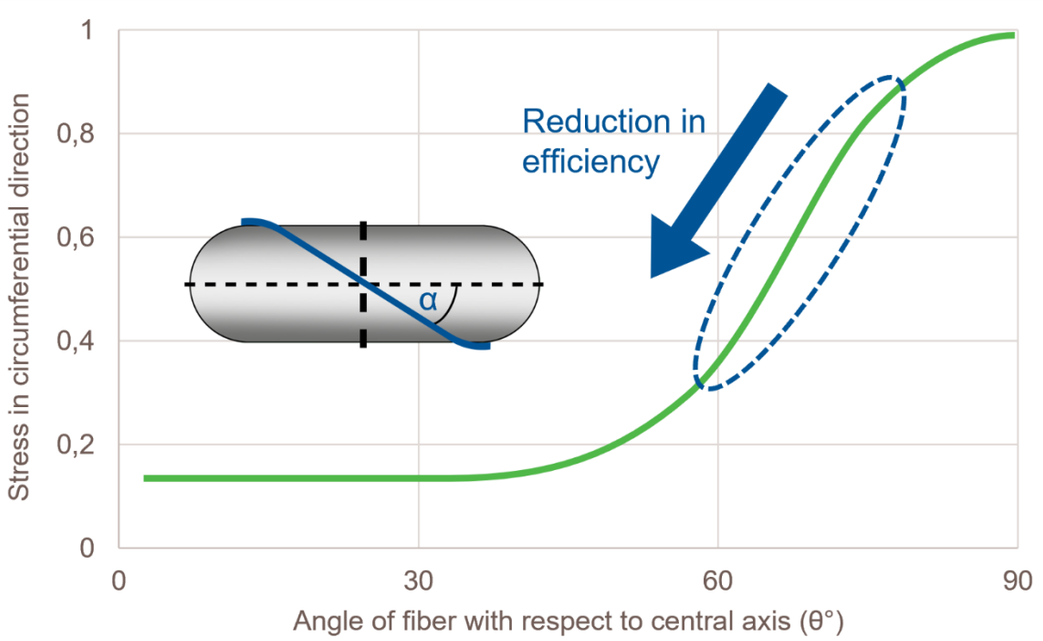
Analysis of winding laminates of pressure vessels shows that high-angle helical layers contribute mostly to the dome section and could be omitted in the cylindrical section.

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)

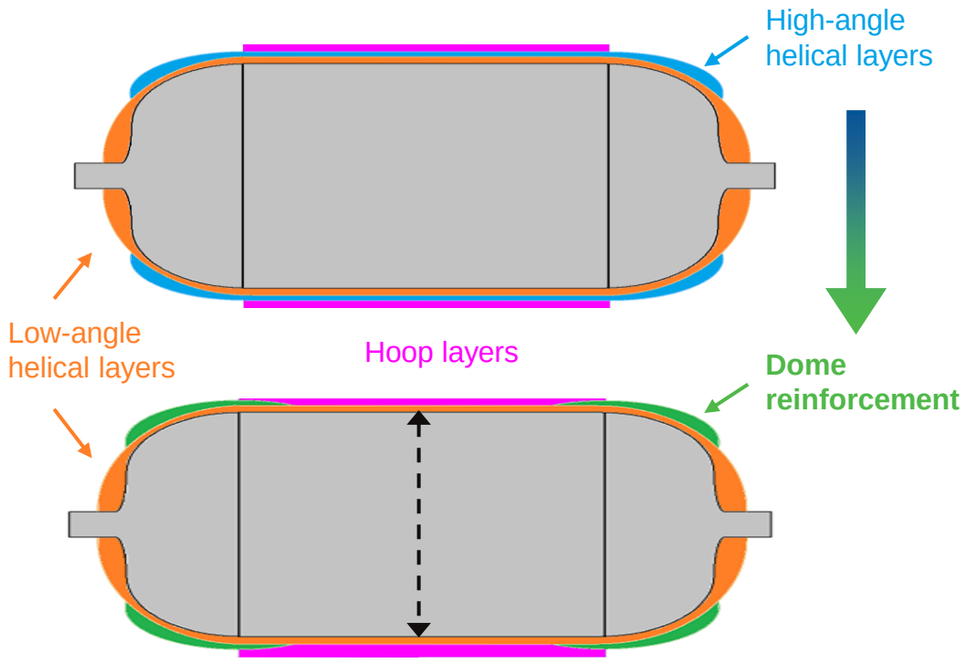


Source: based on A. Fuchs; Toyota Motors Europe; Herausforderungen bei der Massenproduktion von Brennstoffzellenfahrzeugen, 2016

Dome reinforcements for pressure vessels yield 15% material efficiency

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 vessel properties.

Replacing high-angle helical layers with reinforcements



Potential volume increase
given fixed outer diameter / built space

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

"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

Δ 14,6%

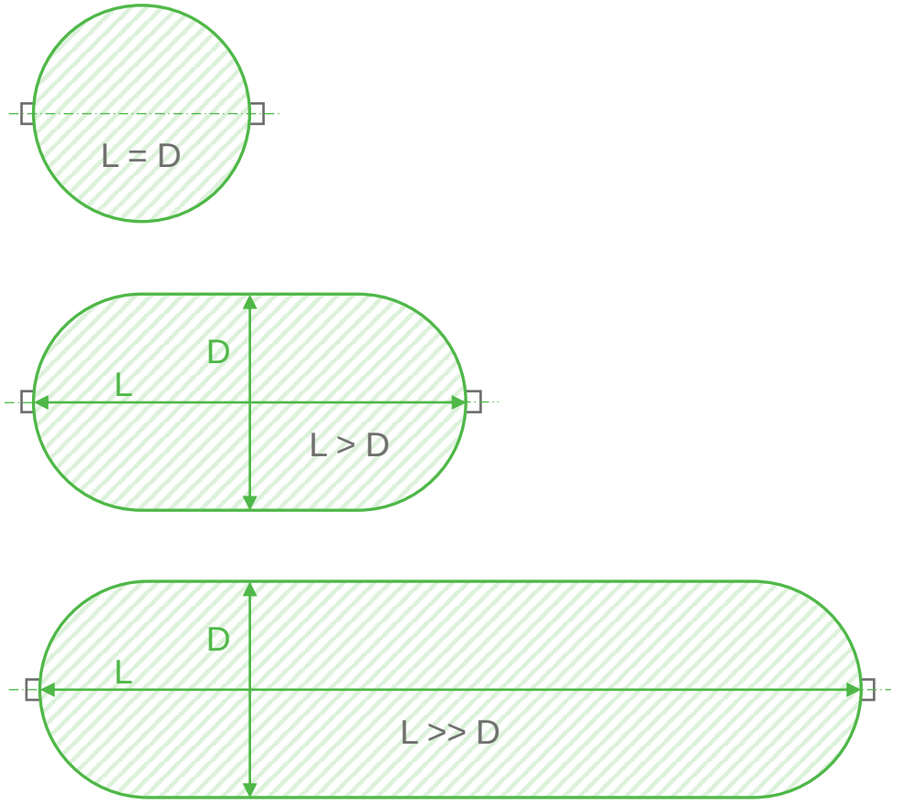
"However, **doilies were eliminated** from the 2015 tank design based on tank manufacturer **[bad] experience with manufacturability**. Doilies may **still represent an opportunity to reduce the carbon fiber** composite, but further work is required to demonstrate and **validate their manufacturability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

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

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



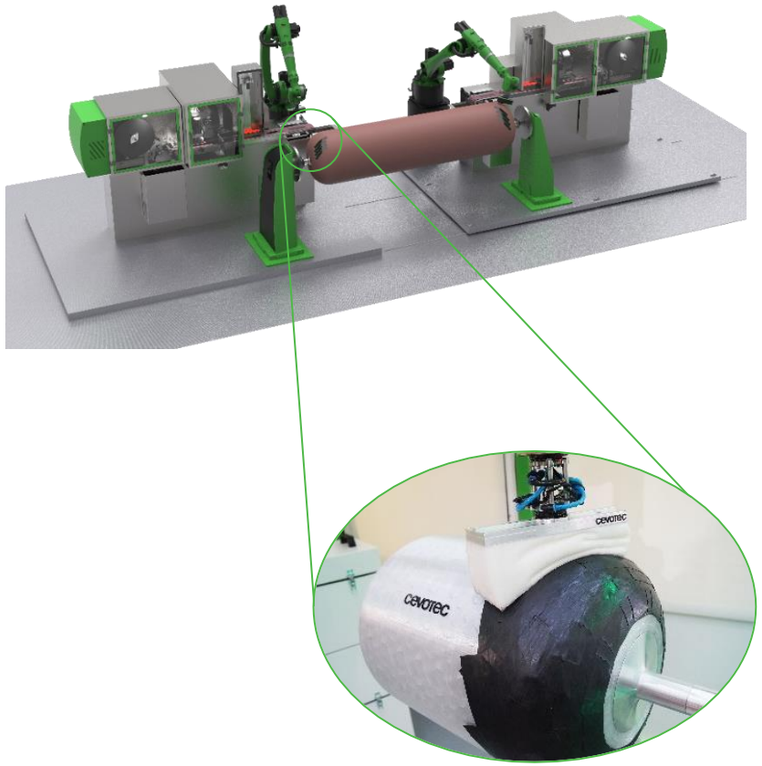
Saving potential for dome reinforcement

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

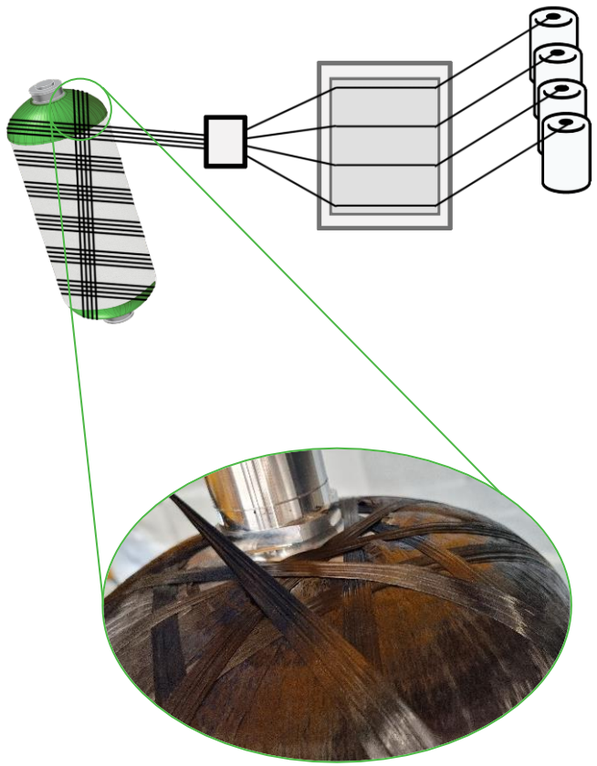
Industrial solution for automated production of tank dome reinforcements

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.

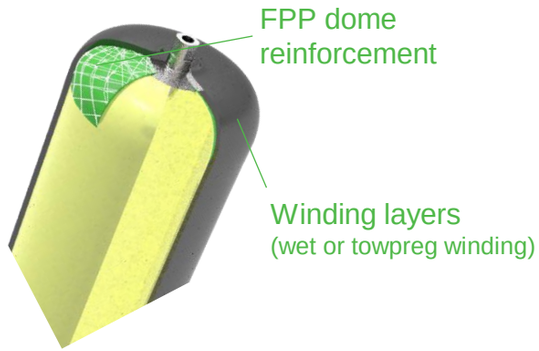
1 Automated liner reinforcement



+ 2 Filament winding (less material)



= 3 Lighter composite tank



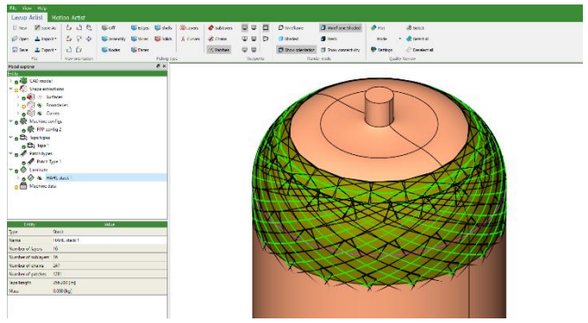
Illustrative savings potential[1]

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

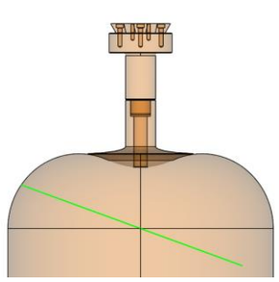
1) Based on larger vessel with aspect ratio > 5

Development process: Dome reinforcements with Fiber Patch Placement

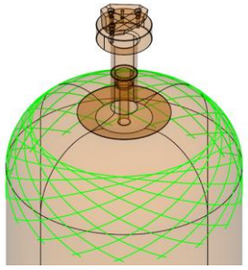
The CAD-CAM software ARTIST STUDIO creates patches automatically along user-defined guide curves. Robots offline-programming is fully automated based on digital twin of laminate & robot cell.



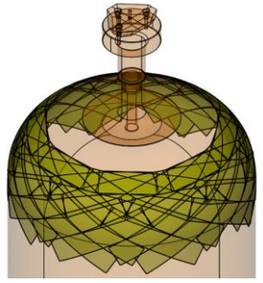
CAD module PATCH ARTIST



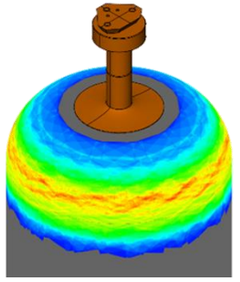
Define
orientations & parameters



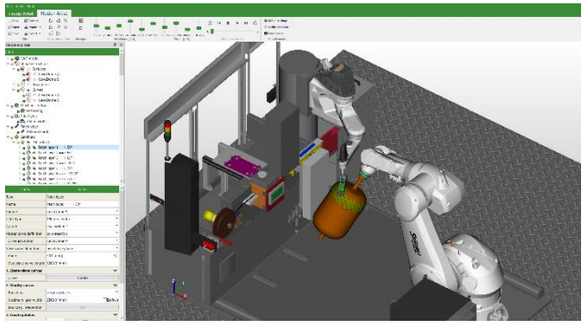
Create
guide curve(s)



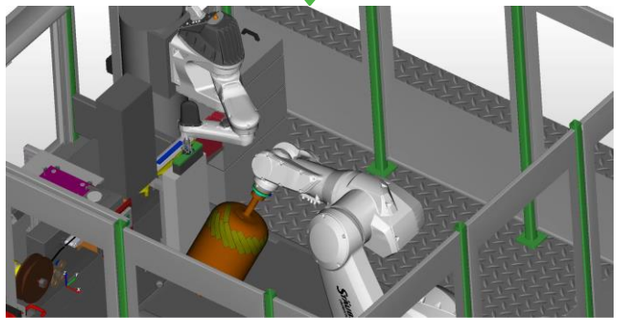
Generate &
optimize laminate



Check
thickness distribution



CAM module MOTION ARTIST



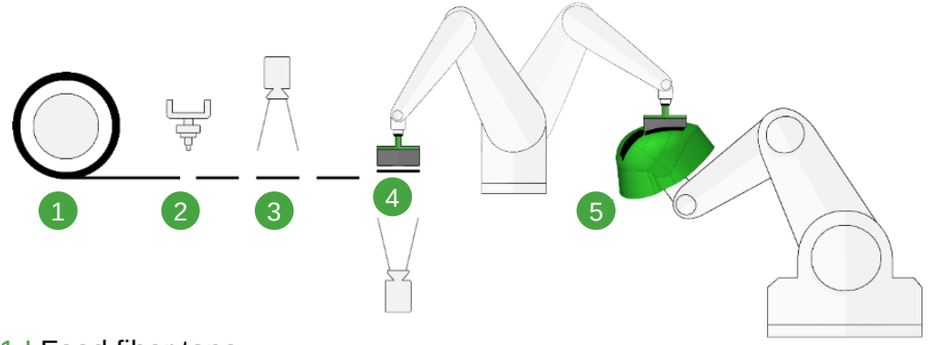
Offline programming & simulation with digital twin

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

Demonstrator production on lab system SAMBA Pro

Watch the full demo video on YouTube

Dedicated gripper technology

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

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%[1] 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%[1].

→ More output / gross margin by line and plant

Better product

Reinforced tanks weight ~15%[1] less and have ~ 20%[1] more storage volume at same built space.

→ Pricing opportunity for first movers

Note: 1) exact savings depend on specific vessel design and production set-up

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	450,60 €	216,10 €
Delta FPP production cost	-45,99 €	-45,99 €
Net benefit replacing HAHL 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% - 20% cost improvement / benefits per composite tank

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

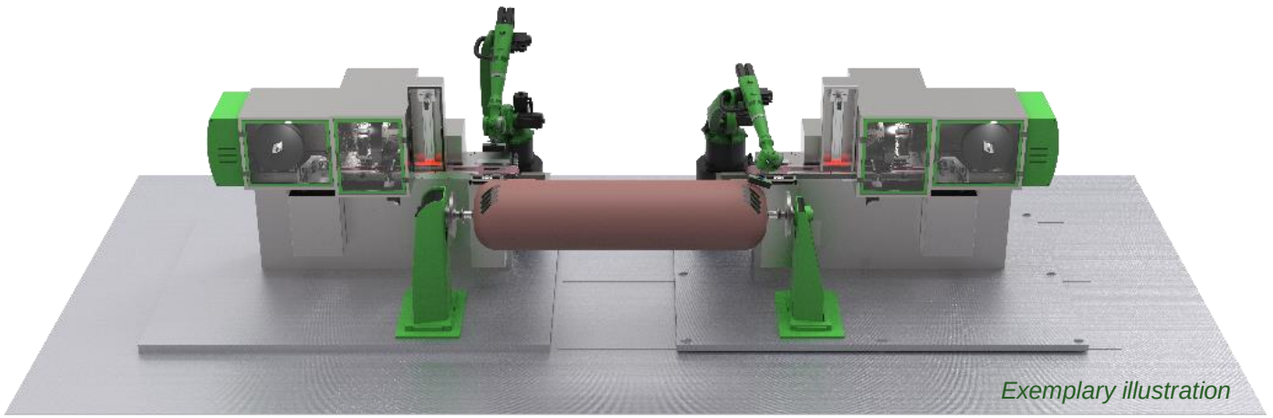
Please contact us for more details on the calculation or to request a sample calculation for your production setting.

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

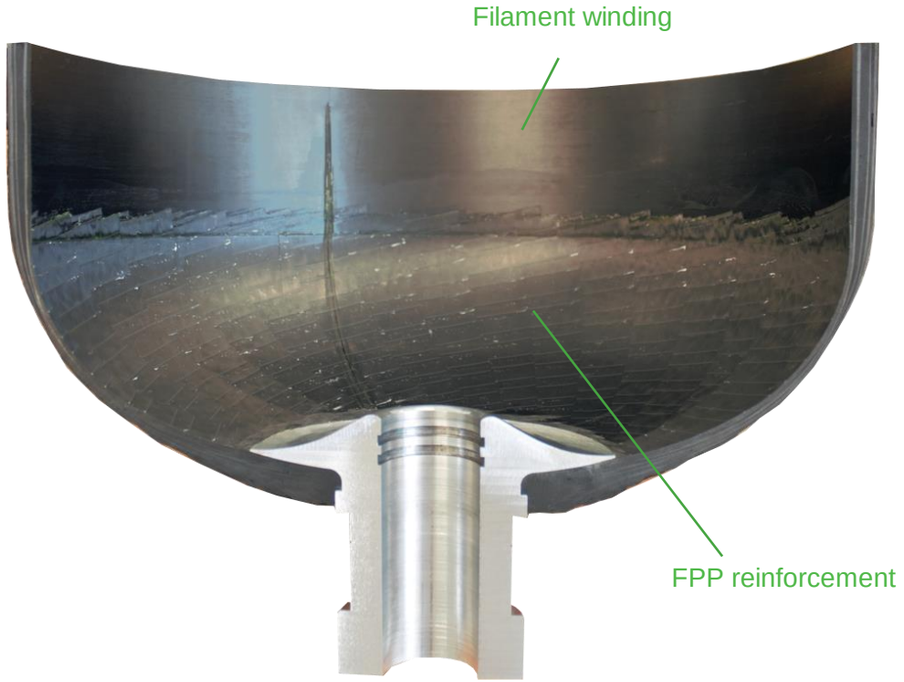
Developing an optimized full-scale demonstrator in a joint project with industry partners.

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
- Final results expected in 2023

Evaluation of impact of FPP dome reinforcements in industrial production setting

Cut-out of first trial lay-up



Summary: Storage efficiency improvement with tank dome reinforcements

Dome reinforcements for composite pressure vessels yield benefits in cost, weight and storage efficiency. Fiber Patch Placement enables industrial production and integration with existing lines.

Composite tank dome reinforcements ...

→ save weight & cost

→ improve storage efficiency

→ are placed fully automated, no post-processing

→ can be used with wet and towpreg winding

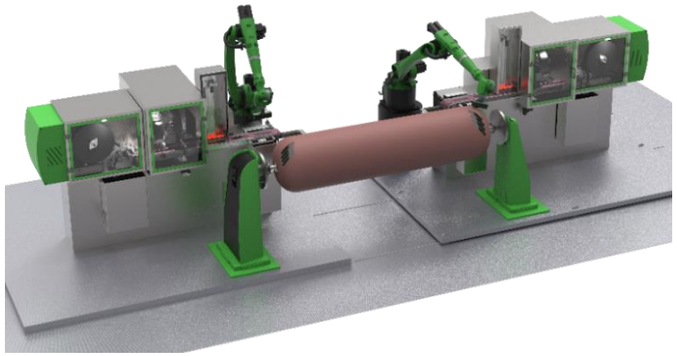
→ improve the sustainability of composite tanks by significantly saving on CF material

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*

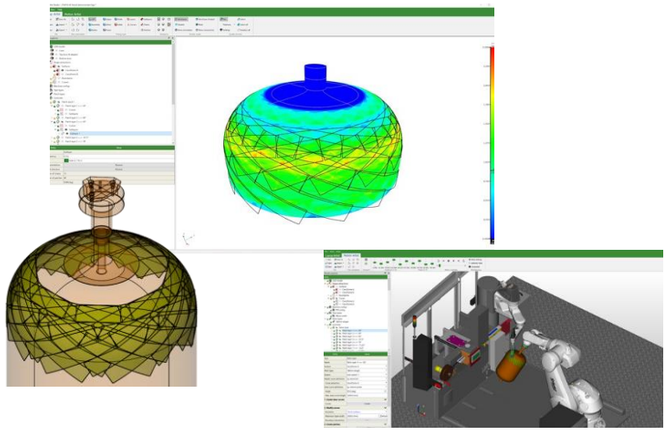
FPP automation platform



- Flexible 3D fiber lay-up platforms
- Configuration tailored to dome reinforcements
- Sensor-controlled & documented process
- Maintenance service & engineering support

ARTIST STUDIO

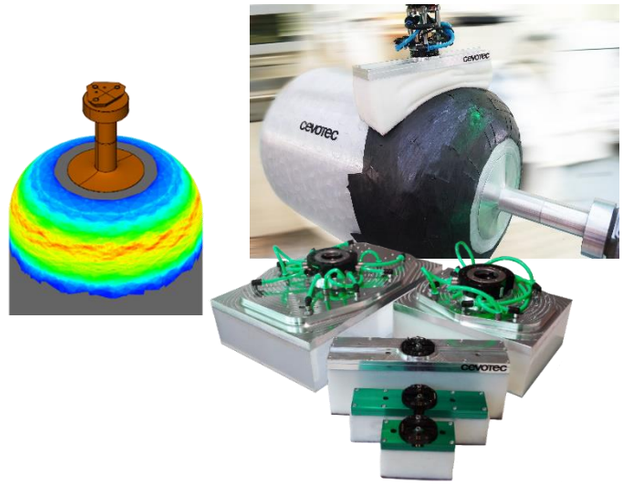
CAE software platform



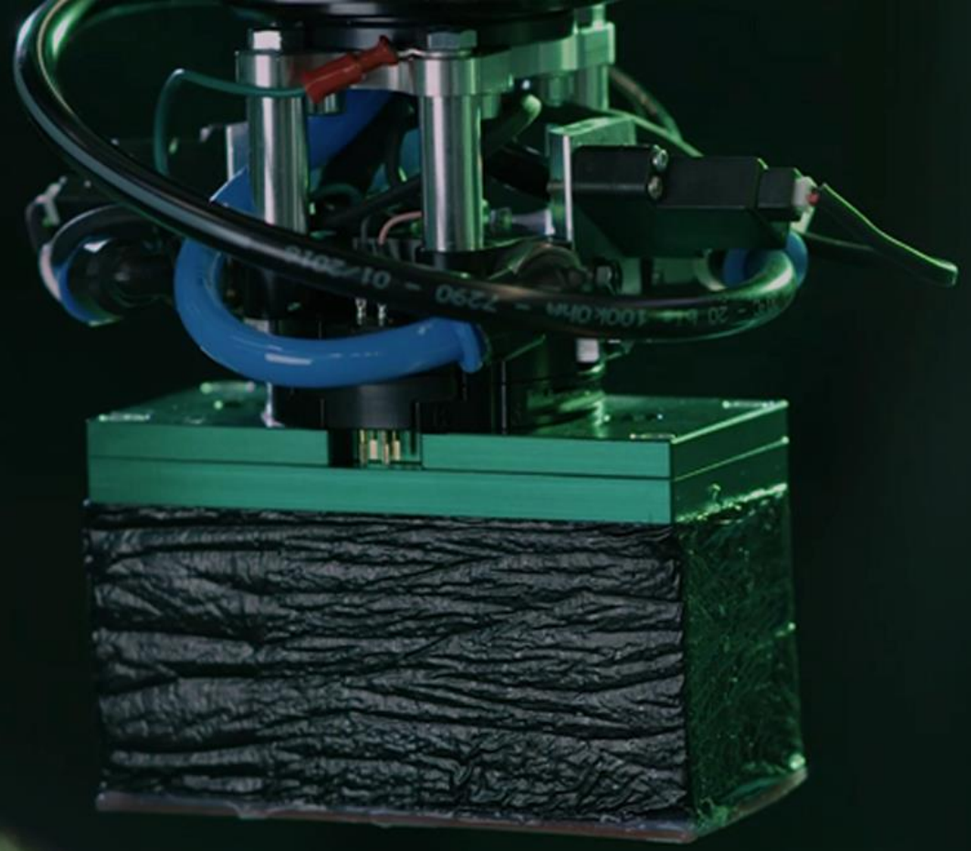
- CAD-CAM for patch technology
- Automated programming of SAMBA systems
- Interface module for FE software available
- Dedicated design features for composite tanks
- Training and consulting for engineering teams

cevoLab

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

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For a lighter, more sustainable future.

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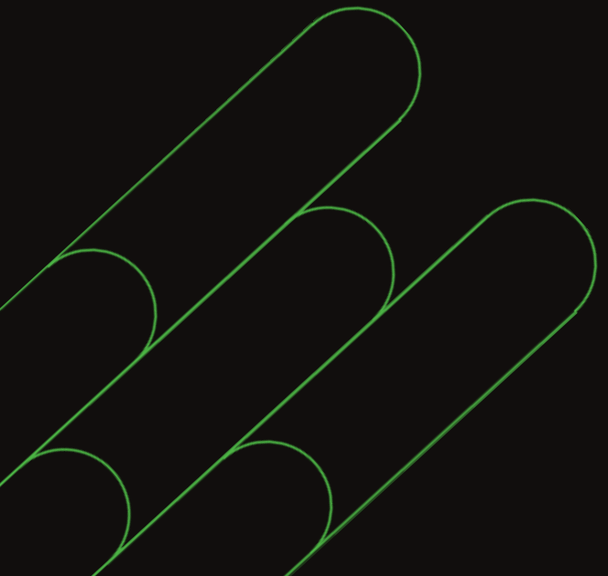

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