
# Dome reinforcements for composite tanks

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

March 2025

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.

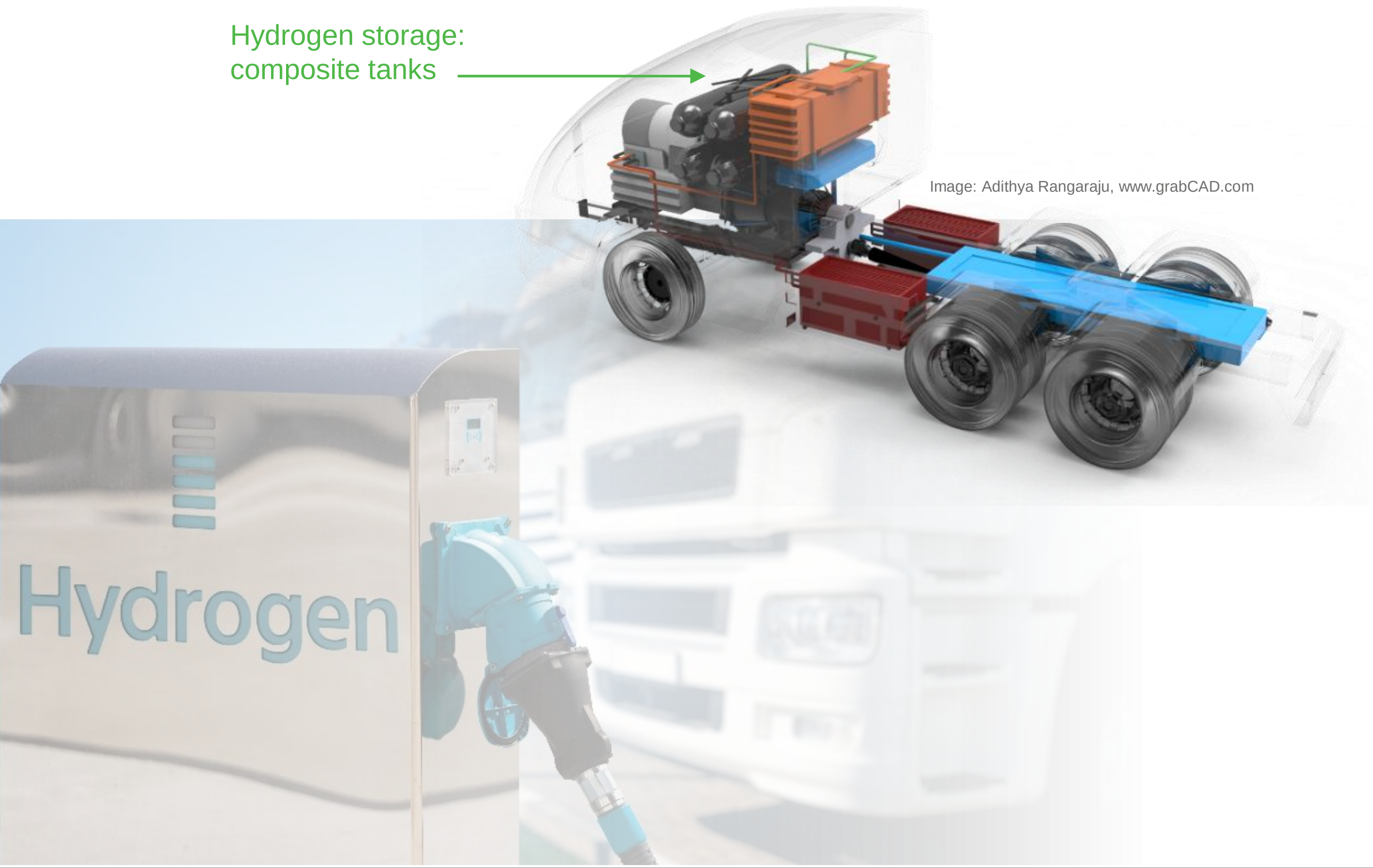
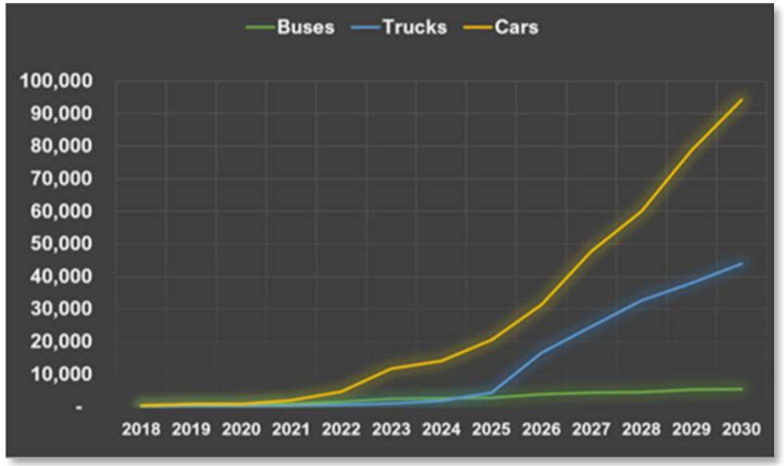



Image: Adithya Rangaraju, www.grabCAD.com




| | 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**

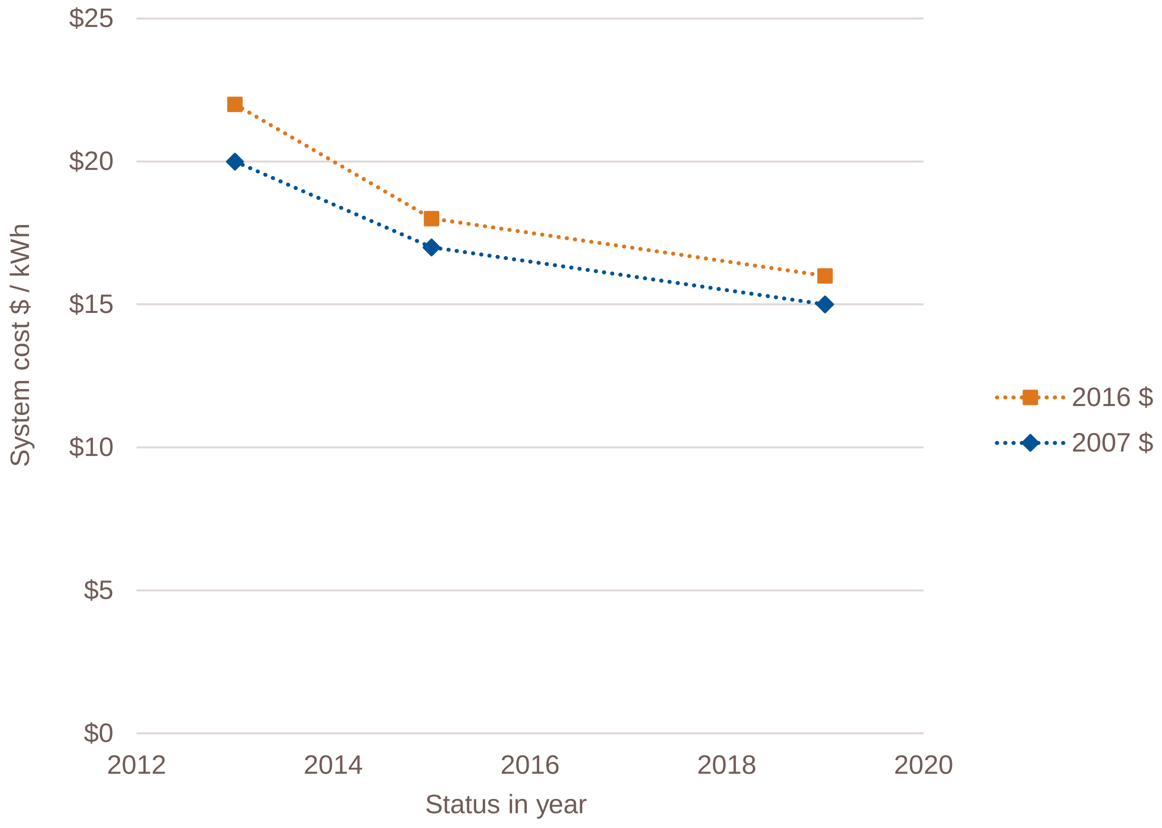
Compare with total global CF market today: approx. 100kt

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

# System cost for mobile storage of compressed hydrogen

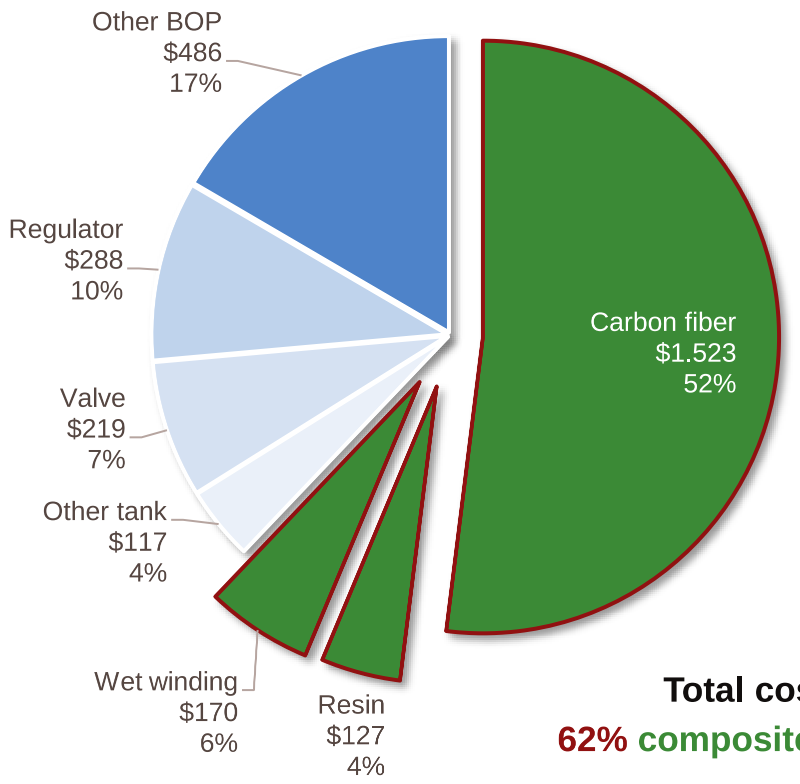
While storage system cost have decreased notably in the last decade, the composite shell is still the largest cost reduction opportunity, representing over 60% of total cost of storage system.

## 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)




**Total cost: $2.930**

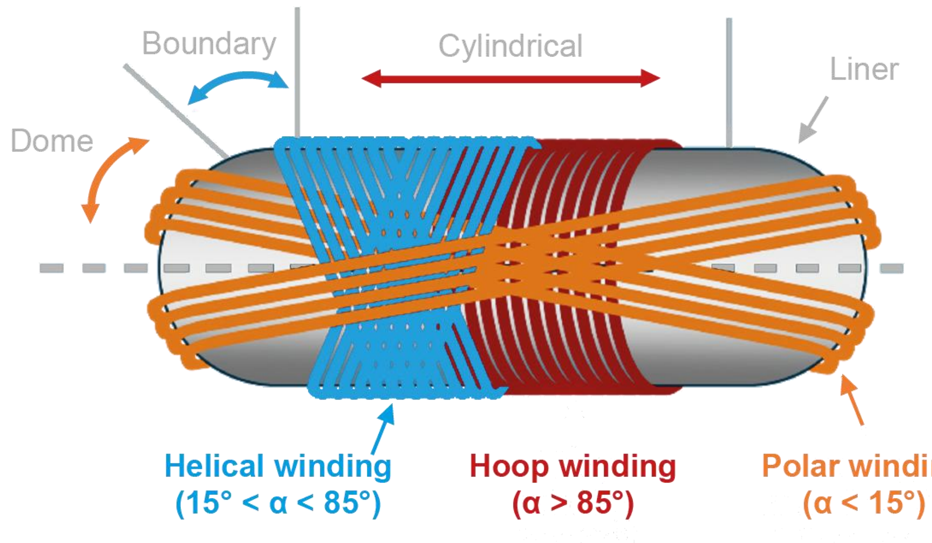
**62% composites: $1.817**

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

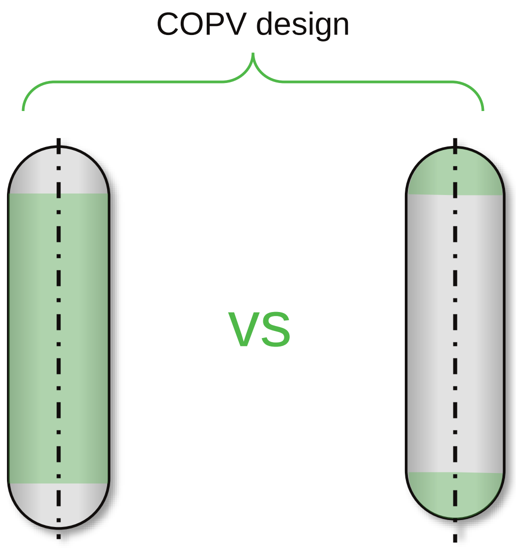
# Fiber angle impact on performance

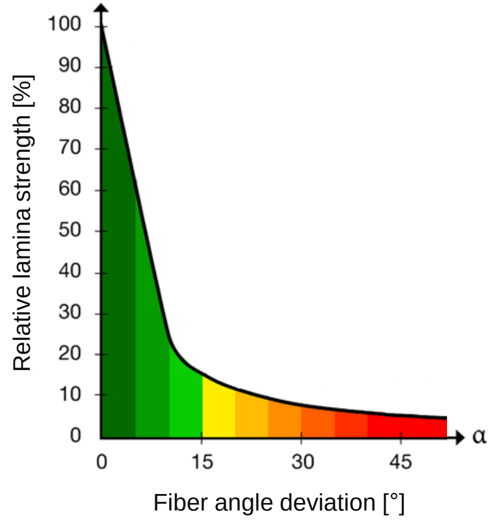
Certain helical winding orientations support the dome area and contribute only marginally to strength in the cylindrical section due to their orientation with angle deviation from principal load.

## 3 types of winding patterns in COPV




## Key consideration for COPV laminate design



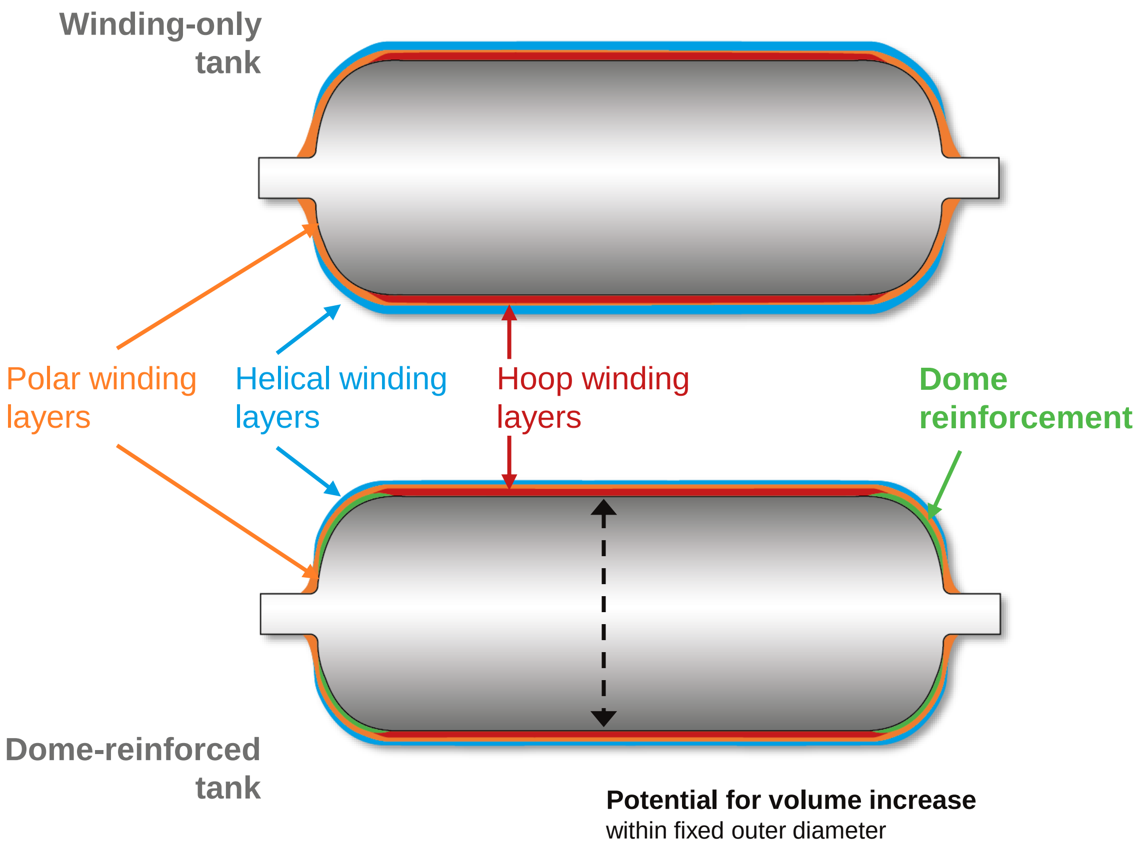

Small deviations in fiber orientation significantly reduce relative strength

▶ **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.**

| | | 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

# 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

Cevotec SAMBA Pro PV-2

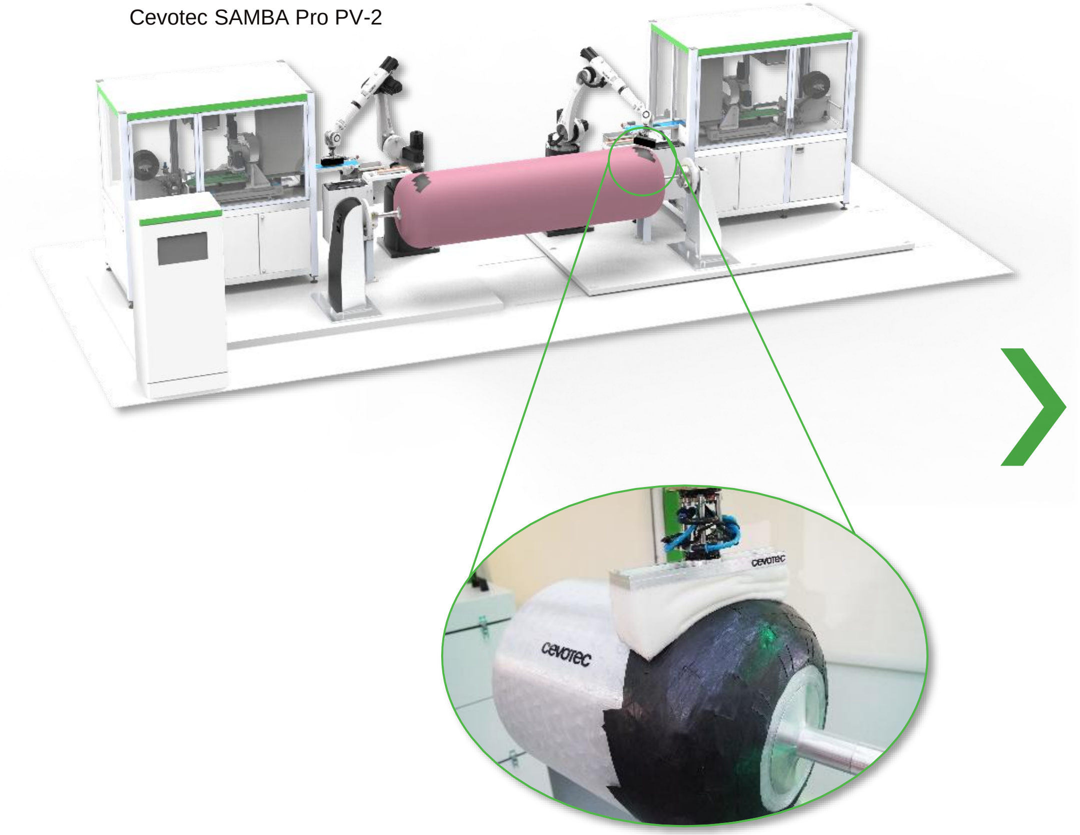
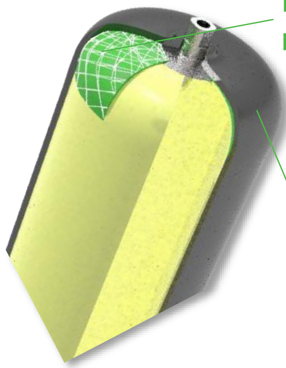


Image: © Roth Composite Machinery




**Illustrative savings potential[1]**

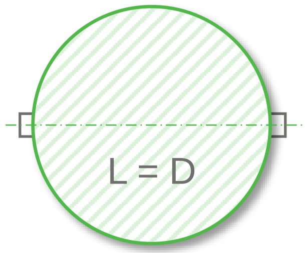
| | |
|---|---|
| **Weight:** | **- 15%** |
| **Cost:** | **- 10%** |
| **Process time:** | **- 15%** |

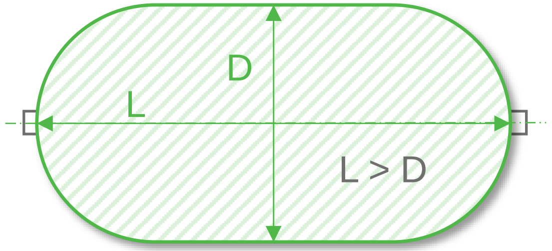
1) Savings potential depend on individual vessel characteristics

# 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

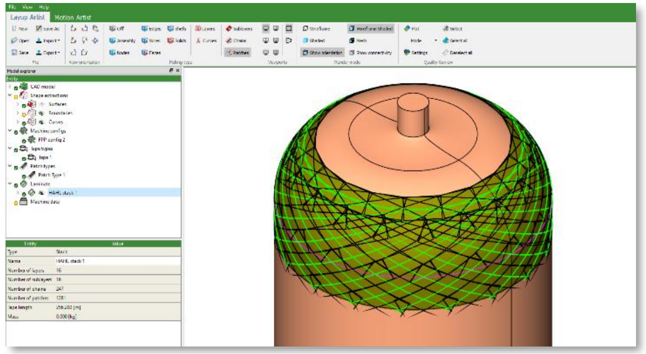
L / D = 1 → No saving potential

L / D > 1 → Saving potential growing

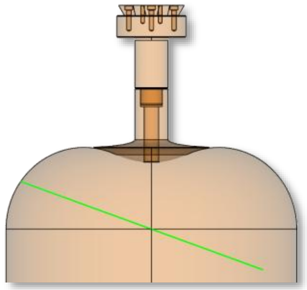
L / D > 5 → Large saving potential

# Product development: Dome reinforcements with Fiber Patch Placement

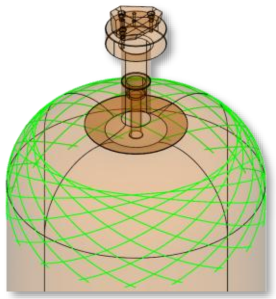
## FPP software ARTIST STUDIO creates patches automatically along defined guide curves and performs automated robot offline-programming. Dedicated design features for dome reinforcements available.



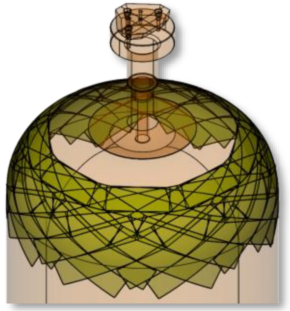
**CAD module PATCH ARTIST**



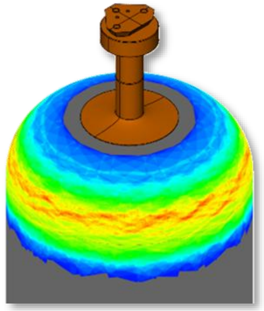
Define
orientations & parameters



Create
guide curve(s)

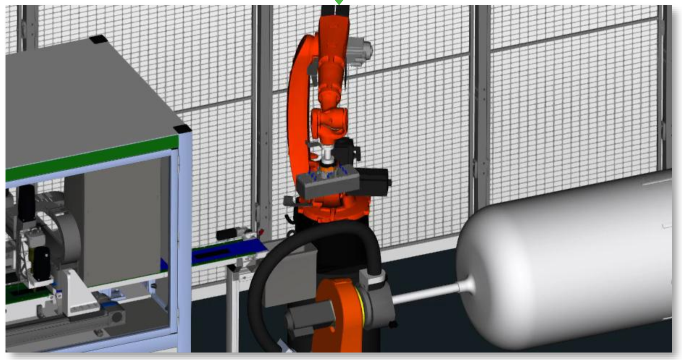


Generate &
optimize laminate

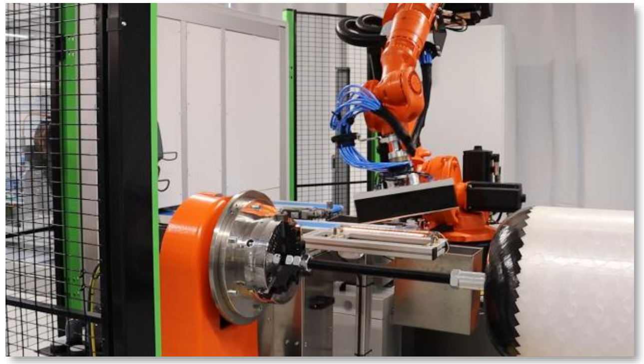


Check
thickness distribution


**CAM module MOTION ARTIST**



Offline programming & simulation with digital twin

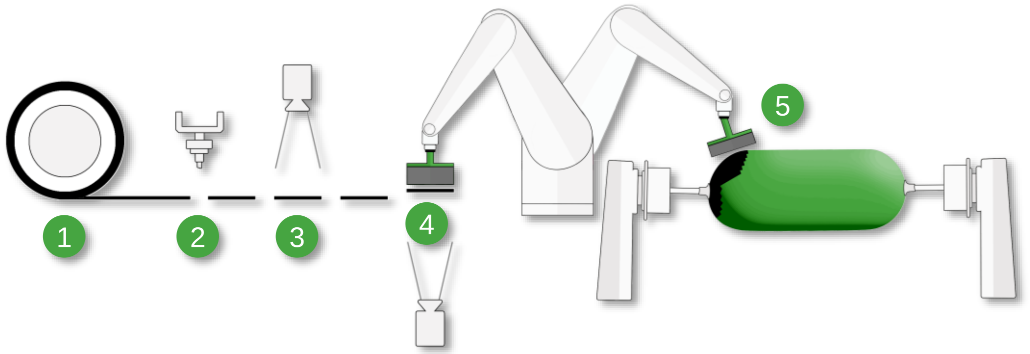


Production on SAMBA Pro PV lab system

# The Fiber Patch Placement process for dome reinforcements

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

## Process overview

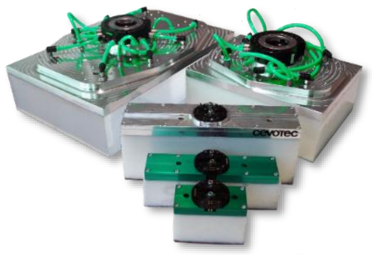



1 I Feed fiber tape
2 I Cut tape into patches
3 I Inspect quality
4 I Pick-up, check position
5 I Place reinforcement patch on dome

## Demonstrator production on SAMBA Pro PV lab system


## Dedicated gripper technology

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

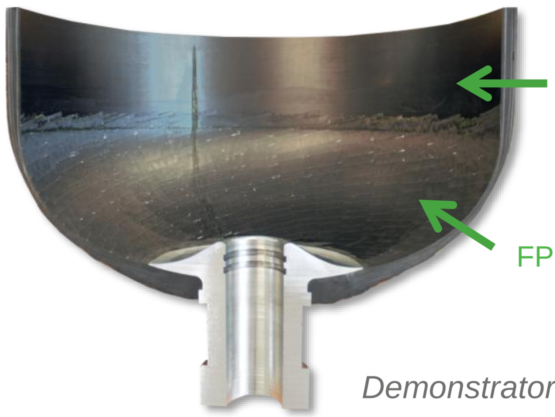


# FPP dome reinforcements evaluated with industry partners

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

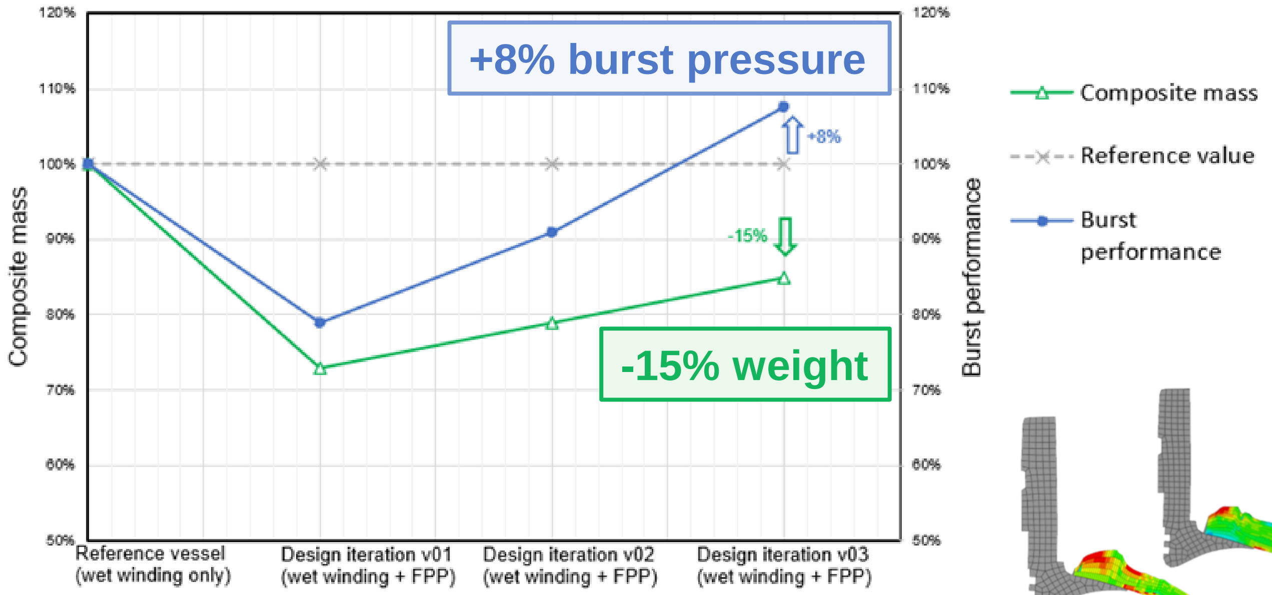
## Project outline & goals

- 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

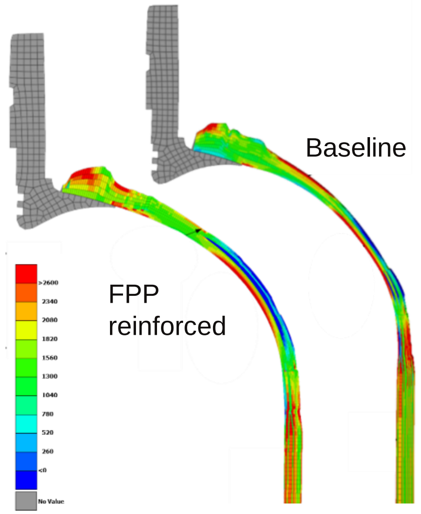



*Demonstrator cut-out*

## Project results



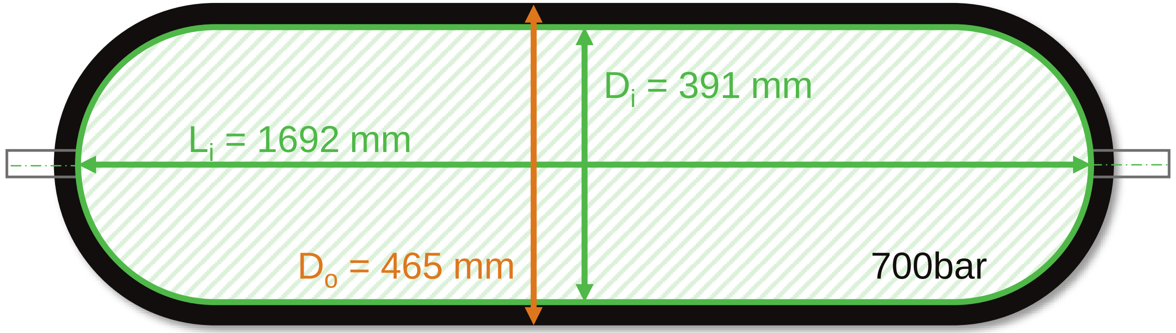

*Burst tests showed an acceptable failure mode*



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

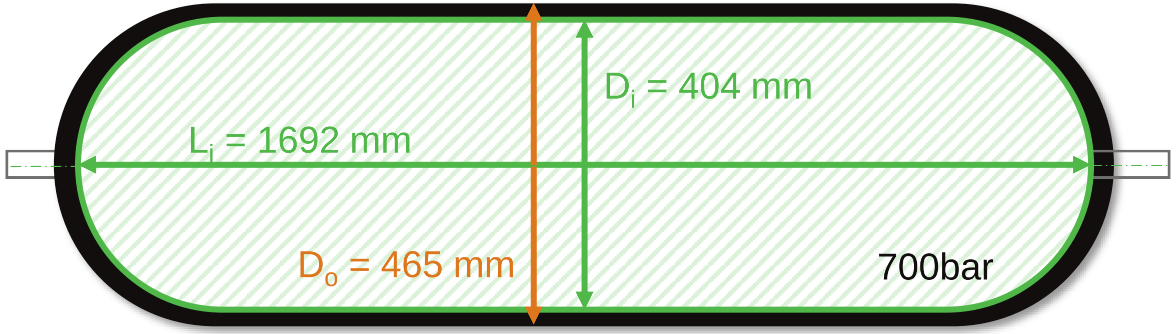
In this example, the reinforced vessel yields a 13% material reduction combined with a potential 7% storage volume increase at same outer diameter, boosting storage efficiency by 19% to 6.5%.

## Case study reference vessel (illustrative)




- $V \approx 180$ l
- Mass CF composite $m_{CF} \approx 116.2$ kg
- H2 mass storage $m_{H2} \approx 7.54$kg (@ 700 bar | 40kg/m³)
- Storage efficiency $m_{H2} / (m_{CF}+m_O+m_{H2}) \approx$ 5.5%

## Dome-reinforced vessel (illustrative)




- Volume, $V \approx 192$ l
- Mass CF composite $m_{CF} \approx 101.2$ kg (-13%)
- H2 mass storage $m_{H2} \approx 8.05$kg (@ 700 bar | 40kg/m³) (+7%)
- Storage efficiency $m_{H2} / (m_{CF}+m_O+m_{H2}) \approx$ 6.5% (+19%)

# 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 approx. 15%. 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 HAHL with FPP** | **404,61 €** | **170,11 €** |
| Delta process time | -11% | -14% |
| Resulting delta in equipment cost FW | 1,82 € | 6,63 € |
| **Net benefit from faster cycle time** | **1,82 €** | **6,63 €** |
| 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 €** | **364,23 €** |
| as percentage to baseline cost (for composite shell) | 14% | 18% |
| **Additional profit margin** (based on assumed 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 € | 3.800.000 € |
| 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 €** | **-4.465.000 €** |
| **Yearly benefits** | **5.939.325 €** | **3.642.332 €** |
| **Payback period (months)** | **10** | **15** |
| Internal rate of return (IRR) | 121% | 79% |
| Net present value (NPV) | 31.769.016 | 16.552.385 |

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-2: FPP 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-2

- 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 customer projects and demonstration**


Watch the full video on YouTube

▶ **Visit our** cevo**Lab in Munich for a live demonstrator of the system!**

# FPP 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

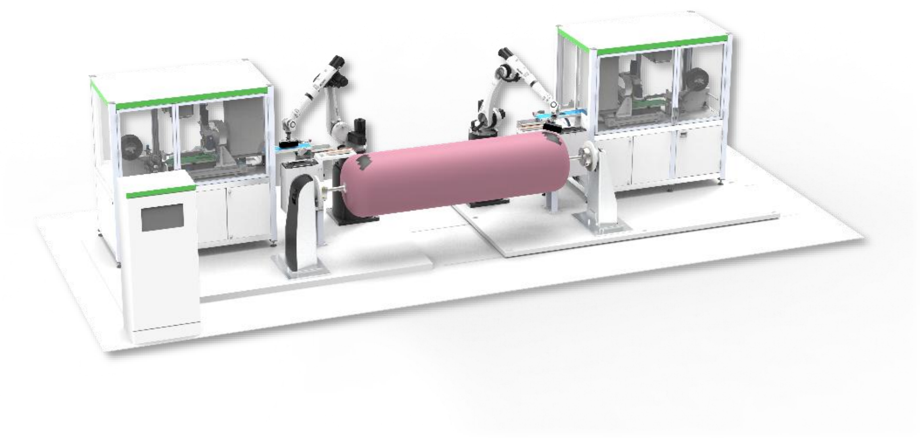
- **improve the sustainability of composite tanks by significantly saving on CF material**

# 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

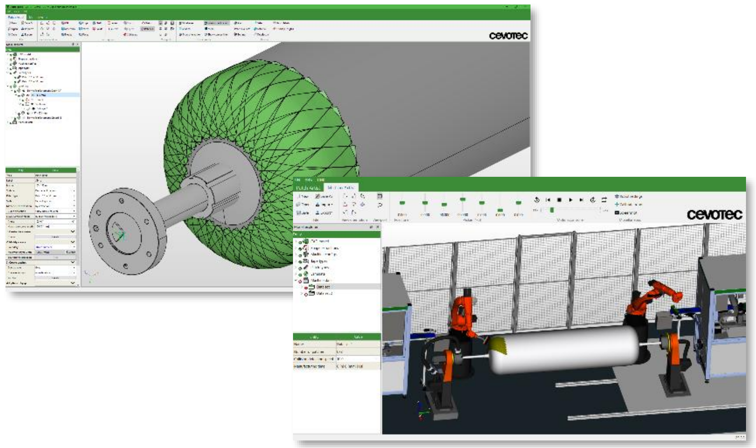
FPP automation platform



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

## ARTIST STUDIO

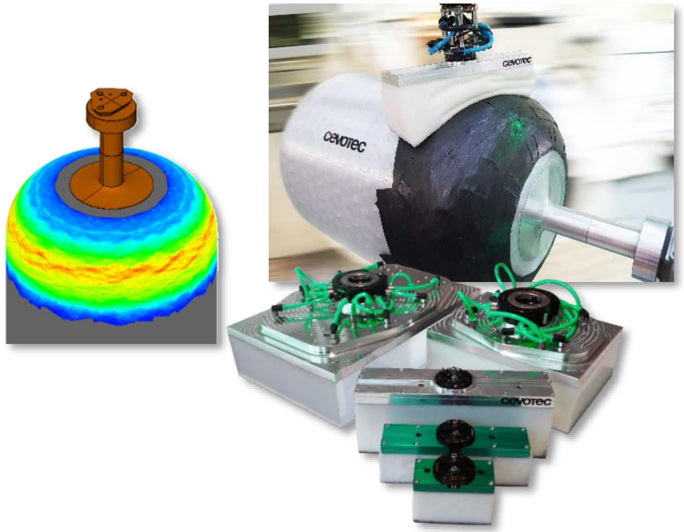
CAE software platform




- 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