ARKEMA

Troisièmes Rencontres académie-industrie

L'Hydrogène vecteur énergétique et réactif chimique

Société Chimique de France

INSTITUT DE FRANCE Académie des sciences

Fondation de la Maison de la Chimie

FRANCE CHIMIE

7 décembre 2023 - Maison de la Chimie

Stockage et transport de l'hydrogène : solutions matériaux composites pour les réservoirs d'hydrogène haute pression

Jean-Paul Moulin
Material Science Director - Arkema

7 Dec 2023

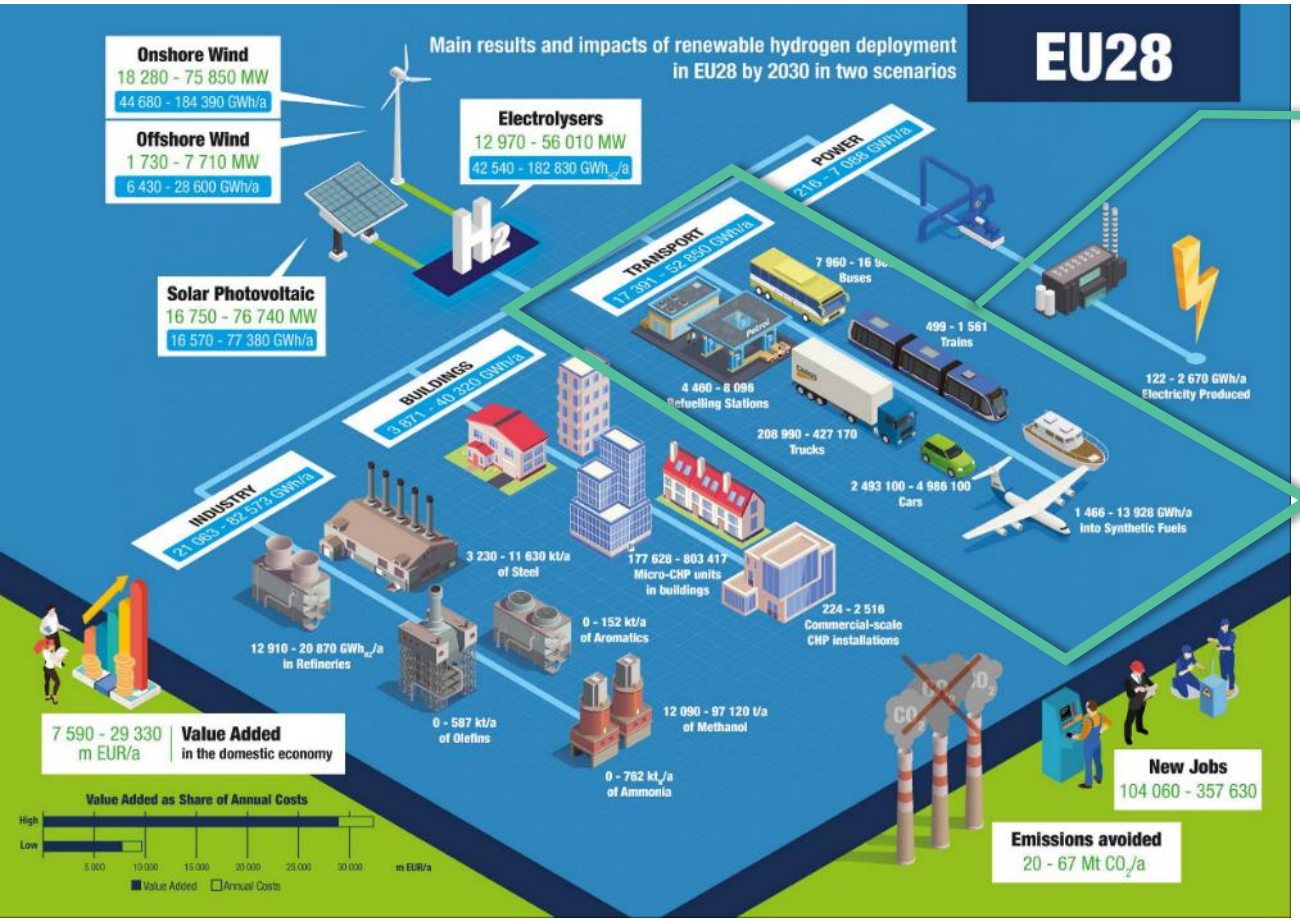
ARKEMA

Solutions matériaux composites pour les réservoirs d'hydrogène haute pression

1. Arkema's hydrogen initiatives
2. Liners for High pressure vessels
3. Thermoplastic Composites Shell
   - Elium® tank type IV
   - UDX® tapes type V
4. SHM sensors
5. Conclusion

7 Dec 2023

Hydrogen – European Roadmap & Arkema Initiatives



Materials for Hydrogen Mobility

- Thermoplastic recyclable type IV & type V **high pressure vessels** for cars, trucks, buses and trailers

- Membranes for **fuel cells**
- Coatings and composites for bipolar plates

- Piezoelectric sensors for high **pressure vessels SHM**

Arkema **M^2H_2** project is part of "IPCEI Hy2Tech", the first ever Important Project of Common European Interest in the hydrogen sector

2

Rilsan® Liners for High Pressure Vessels

RILSAN®

Arkema's flagship Rilsan® PA11 - overview

RILSAN®

1

High performance material with 30+ year track record in many demanding markets

Transport

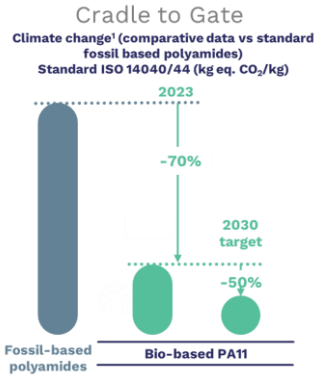
O&G pipes

2

100 % biobased with secure availability and responsible sourcing of castor beans

3

A lower carbon footprint and ambitious decarbonization goals



4

Global production network with **2 monomer** plants (Europe, Asia) and **4 polymer** plants

5

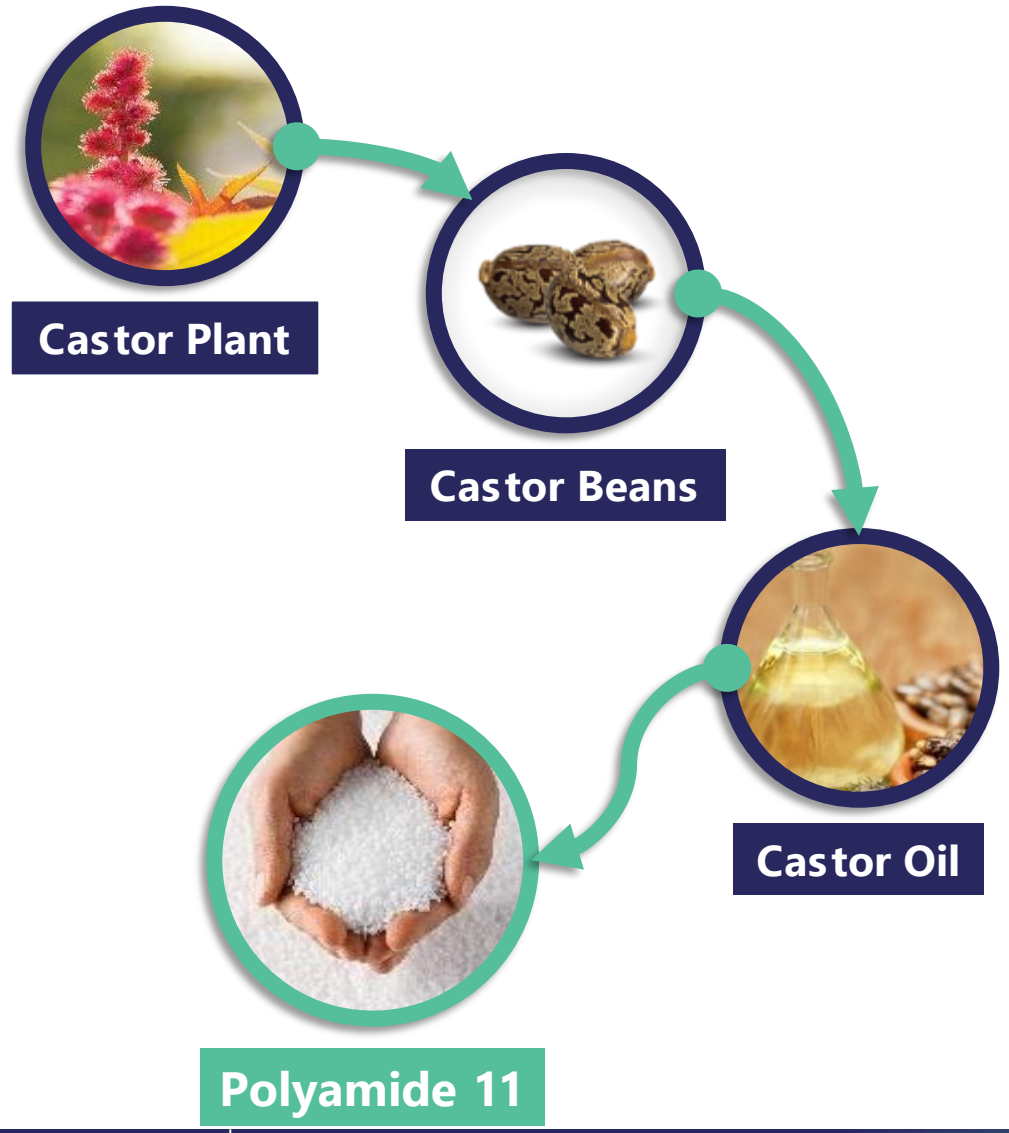
Demonstrated capacity to invest: >450M€ announced in last years to increase capacity by **+50%**

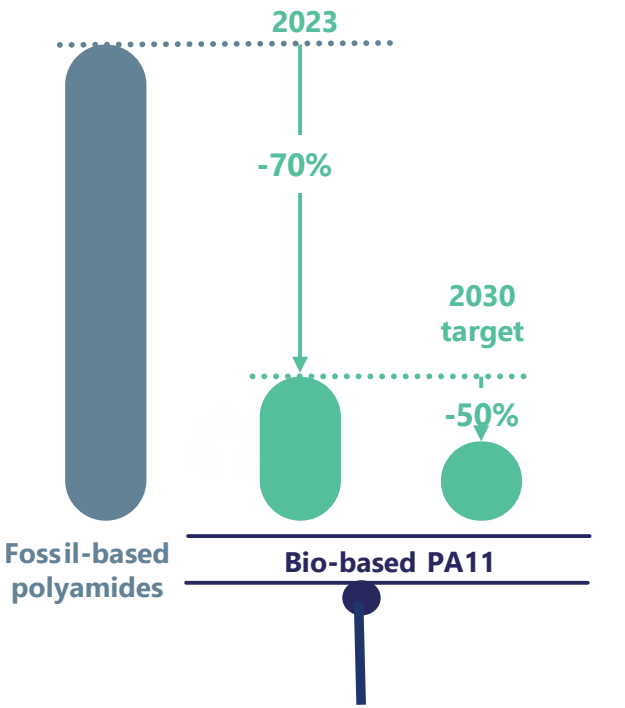
6

Leading recycler of high performance polymers Acquisition of Agiplast in 2021

AGIPLAST
COMPOUNDING FOR TOMORROW

Arkema is reducing the carbon footprint of Polyamide 11

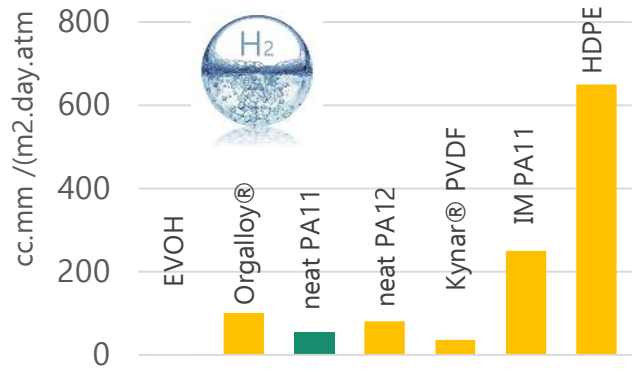




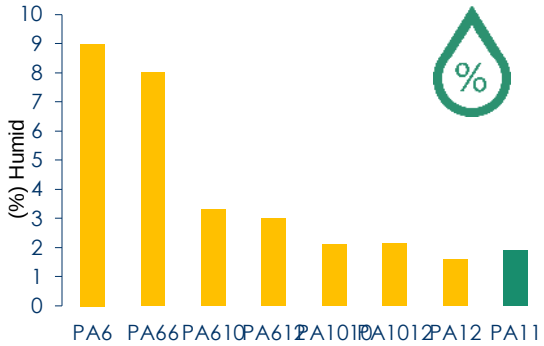
Biogenic carbon impact
and
Biomethane energy use

Rilsan® PA11 Hydrogen Tank Liner

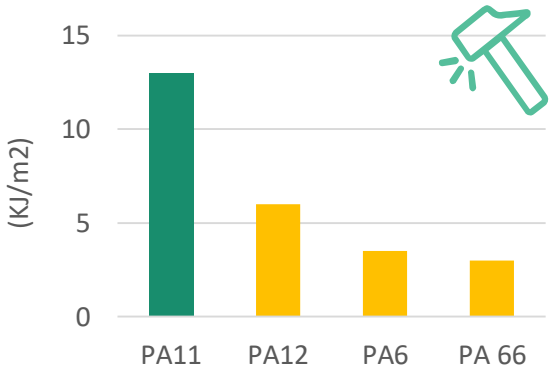
A balanced set of properties



Low H2 permeation



Low moisture uptake



Impact resistant

Adapted to main processes

Rotomoulding

All tank sizes
Low CAPEX

RILSAN®

➔ **high processability**
➔ **mechanical performance**
Techno for **boss-to-liner adhesion**

Blow Molding

High productivity
Multi-layer structures

No oxidation
(high quality weld line)
Stable process for **large liners**

Extrusion - Welding

Long tanks
Thickness control

Wide portfolio of solutions
Weldability
Large tube extrusion experience (O&G)

Kautex Maschinenbau
Kautex has produced a 320 litre hydrogen liner through blow moulding.

3

Thermoplastic Composites for High Pressure Vessels

Advanced Materials : High Performance Thermoplastic Composites

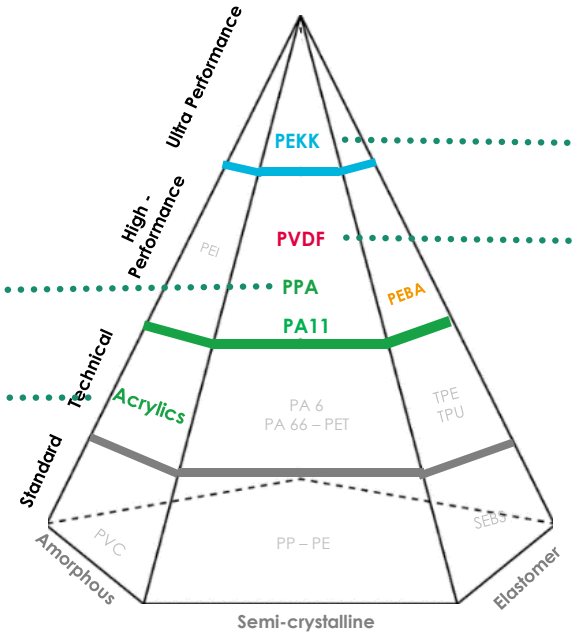
Main thermoplastic polymer base chemistry

RILSAN® MATRIX

- **Carbon fiber / PA & PPA UDX® Tapes**
- **Main Market:** Automotive & Hydrogen

ELIUM®

- **Liquid reactive acrylic resins**
- **Main Markets:** Wind energy, Transportation, Building & Infrastructure, Sport & Leisure



KEPSTAN®

- **PEKK powders for composite manufacturing**

Collaboration agreement Carbon/PEKK UD tapes for Aeronautics & Space. HEXCEL

ARKEMA/BARRDAY® JV UD tapes for Oil and Gas. BarrFlexTU

KYNAR®

- **PVDF powders for composite manufacturing**

Lightweighting & Material Design

Thermoplastic composites solutions

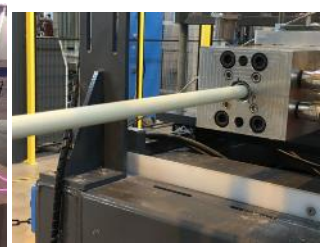
Lightweighting & Material Design

→ ELIUM®

Thermoplastic composites with thermoset like processing technologies

- **Substituting thermoset** resins for high level of **recyclability** (chemical or mechanical)
- A **large range of composites processing** technologies : RTM, SMC, Pultrusion, wet-winding…
- Thermoplastic process possibilities : post forming welding…



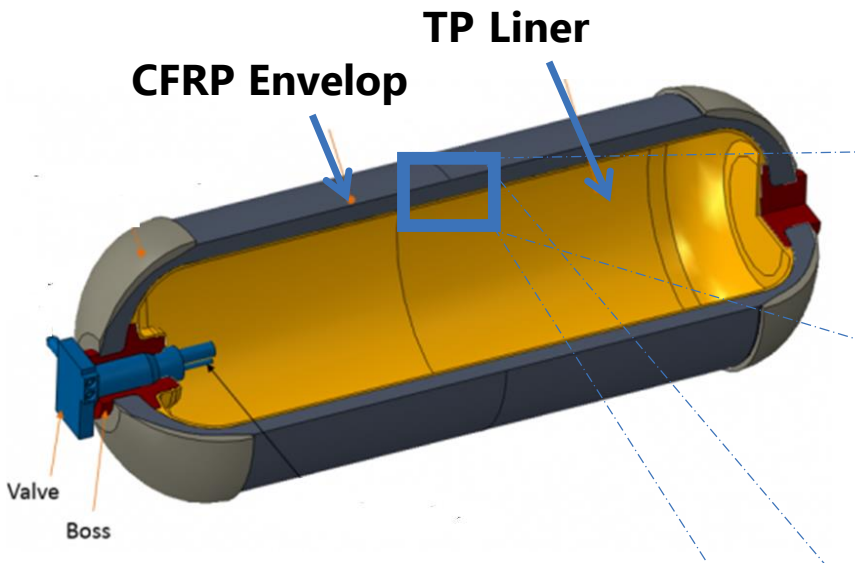
→UDX® tapes

High performance polyamide-based unidirectional fibers tapes for demanding applications

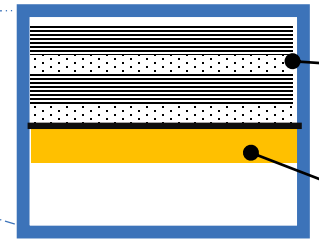
- Unique **biobased high-performance polymers or PEKK** and fibers **impregnation** process for high mechanical performances tapes
- Fast development of **automatized thermoplastic tapes processing technologies** : robotized fiber placement (AFP, ATL..), and hollow body (winding, braiding…) associated with injection molding productive process.




ARKEMA material choice for Type IV & V tanks



Type IV : TP Liner + TP Composites



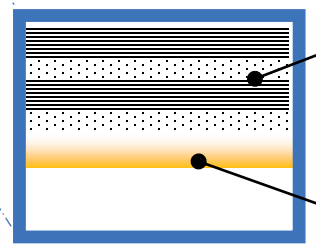
Material

- Carbon / Elium® winding ELIUM®
- Rilsan® Liner RILSAN®

Process

- Tape winding + UV / Heat (dual cure)
- Rotomoulding Blow molding or injection + welding

Type V : TP Continuous – monolithic structure



Material

- Carbon / PA or PPA UDX® tapes RILSAN® MATRIX
- Rilsan® Liner RILSAN®

Process

- Tape winding + heat (Laser, IR….)
- Tape winding or molded + heat for 1st layer miscibility

TP COMPOSITES ADVANTAGES

- Better fatigue / resistance to cycling vs thermosets
- No explosion at burst test : melting & H2 jets (directional)
- Recycling abilities
- Manufacturing : important lead time reduction

H_2 high pressure vessels : thermoplastic composites winding

Elium® wet winding

ELIUM® C599 E resin

- UV Photoiniator and Peroxide
- Productivity improvements :
  low viscosity and low post curing time

UDX® polyamide tapes winding

High Payload Hydrogen Trailers with New Composites Cylinders - European Roadtrhyp project

- New thermoplastic composite tubes (Type V) to maximise the quantity of H2 transported
  - payload of 1.5 ton of H_2 with 700 bar tubes
  - Recyclable thermoplastic material
  - https://road-trhyp.eu/

ROAD TRHYP

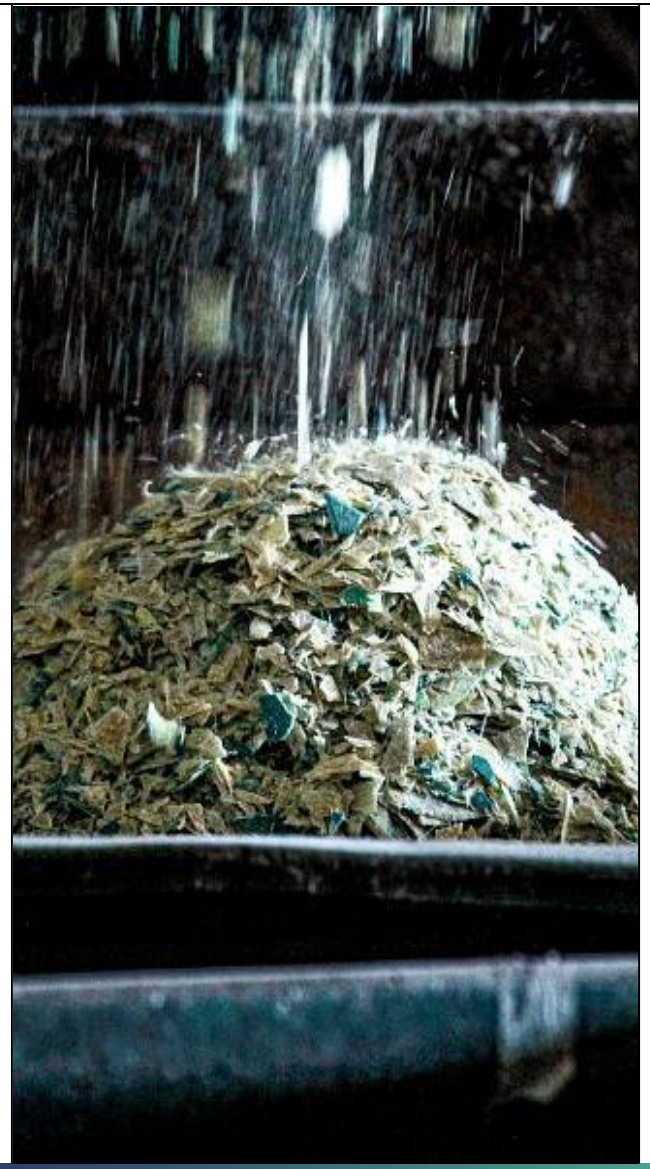
Air Liquide ARKEMA COVESS Efectis ENVITEST INSTITUT P' Politechnika Wrocławska SEGULA

This project is supported by the Clean Hydrogen Partnership and its members. It has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N°101101142.

Elium® the liquid thermoplastic resin designed for recycling

CHEMICAL
RECYCLING

- Unique property of Elium® resins to be **de-polymerized** thanks to a thermolisys process
- Separation of resin and fiber reinforcement
- Collection of the original monomer of the resin
- Possibility to reuse the monomer to create the new resin in a **close loop** recycling process



MECHANICAL
RECYCLING

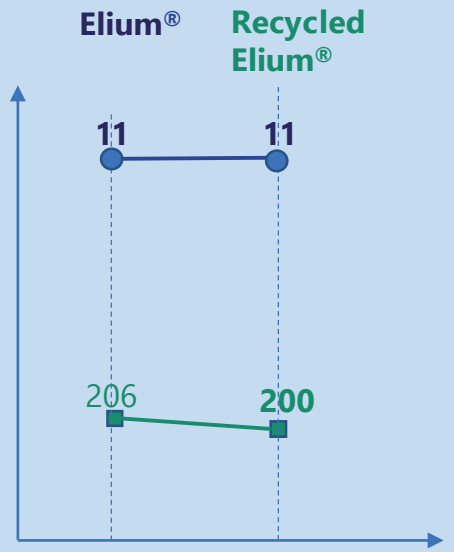
- Grinding and blending with a virgin thermoplastic *(PMMA, ABS, PVC…)*
- Reuse in deposition or extrusion process
- **Enhanced properties** compared to host matrix

Mechanical Properties of Elium® materials

Depolymerisation
Circularity

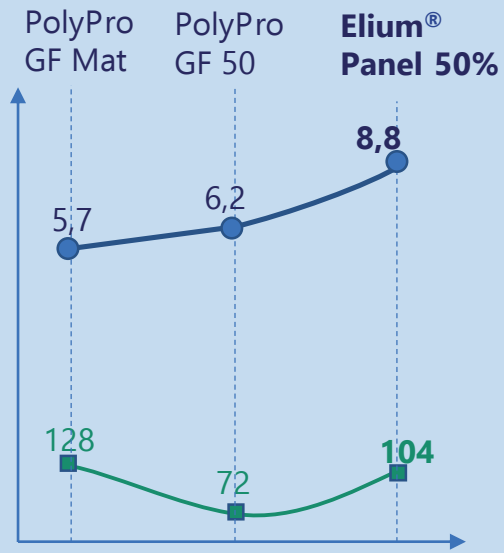
Mechanical Compounding
Upcycling

Tensile Modulus in GPa
Tensile Strength in MPa



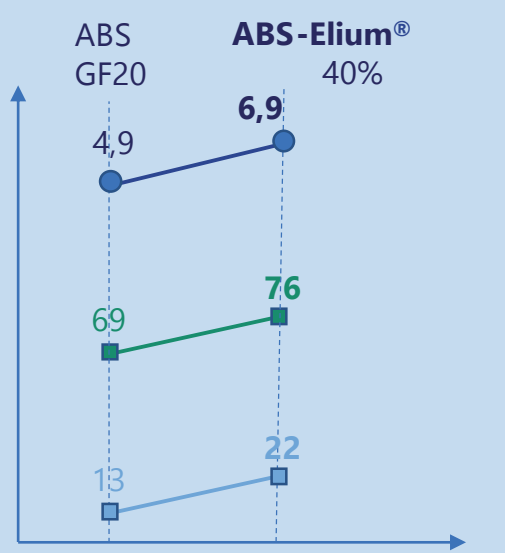
*Properties are based on Elium®,
Glassfiber NCF Biax 600 +/- 45°, Fiber content 46.7%

Flexure Modulus in GPa
Flexure Strength in MPa



*Properties are based on Elium®,
Coupons made by compression

Traction Modulus in GPa
Traction Strength in Mpa
Charpy Impact in kJ/m²



*Properties are based on Elium®,
Coupons made by injection

4

Structural health monitoring of hydrogen tanks

PIEZOTECH

UNIQUE FEATURES

3 MAIN FEATURES

Piezotech® FC

Piezoelectric
Conversion of mechanical energy (stress, strain) into electrical energy (voltage, current) and vice versa.

Printable
We develop a range of high purity polymers and inks adapted to various printing techniques to obtain thin and homogeneous layers.

Customizable
Flexibility of Piezotech products is paving the way for high degrees of freedom in terms of size, shape, number of sensing elements and substrates.

PIEZOTECH® FOR SMART COMPOSITES (H_2 tanks use case)

WHAT

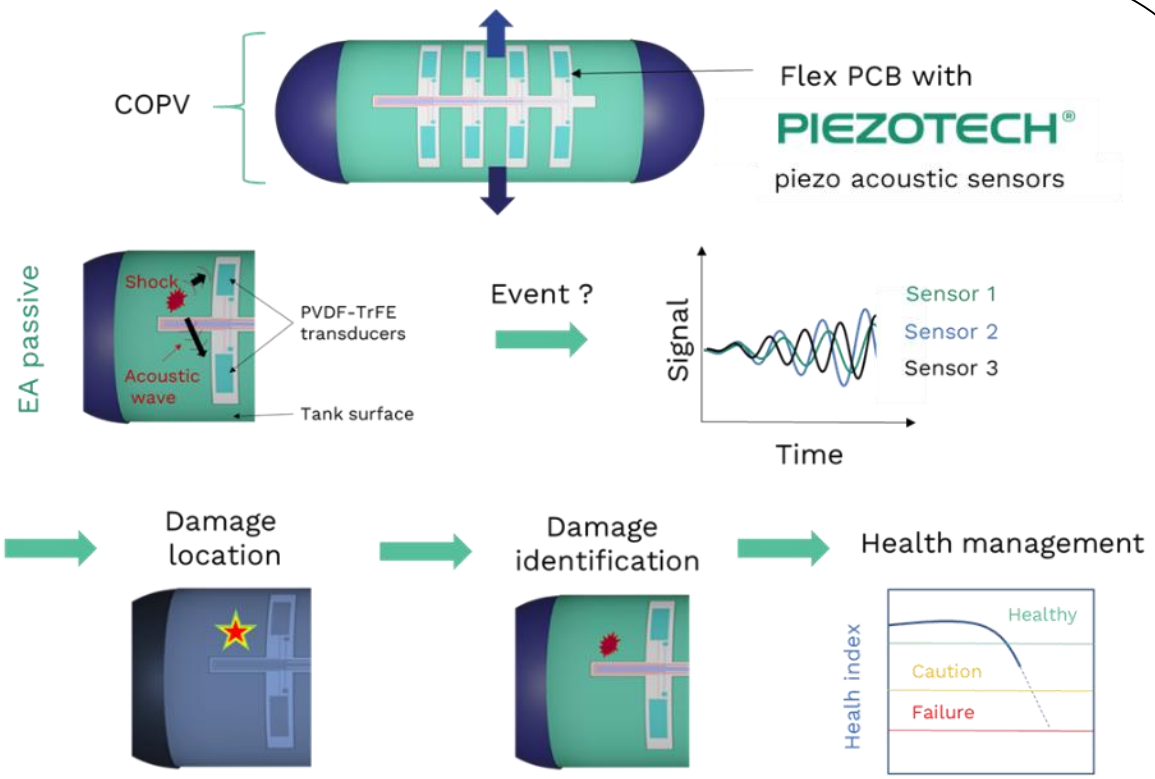
Record and localize **acoustic waves** resulting from mechanical modifications of the composite using **piezo-active polymers (SHM).**

FOR

Detection of **a brutal event** (impacts/shocks, strain, pressure etc.).
Detection of **a premature wear/degradation** (delamination, cracks, fatigue etc.).

WHEN

When the tank **fills/empties**.
When the tank **suffers a shock** (damage from an object on the road etc.).



WHY

Security

Increasing the security of tanks by **fatigue identification**
Realizing the **requalification** of the tank in real time

Optimal costs

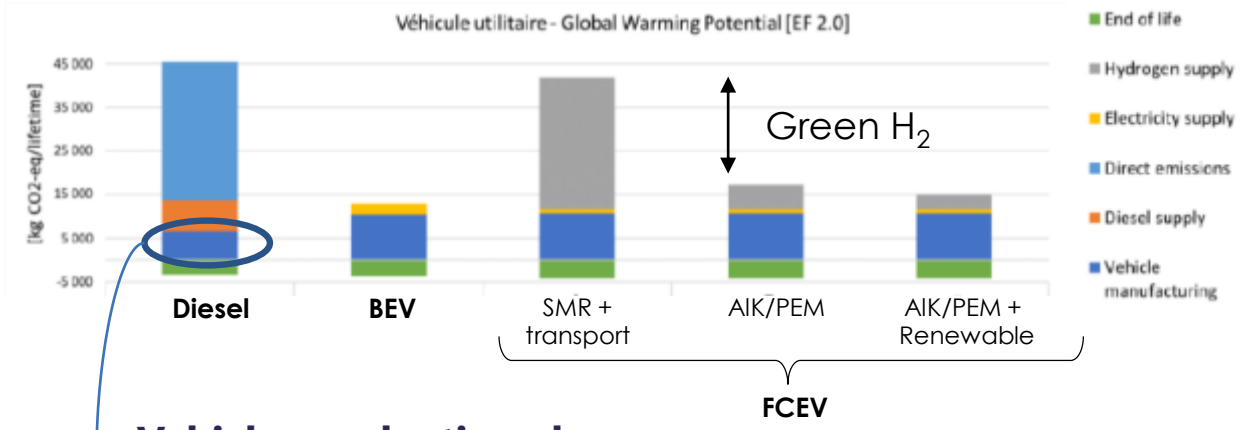
Optimizing the cost by **optimizing the amount of carbon**
Measuring the residual life of the tank for **second life use**

5

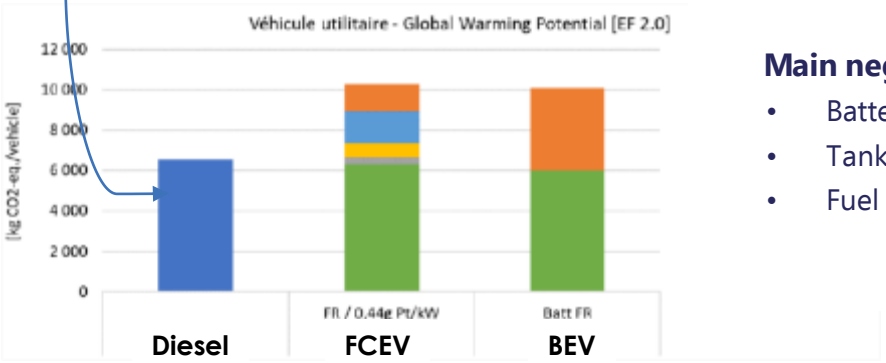
Conclusions

As a conclusion – Hydrogen mobility and Sustainability

→ LCA FCEV – ADEME 2020*



Vehicle production share



Main negative impacts

- Battery
- Tanks H_2
- Fuel Cell (incl. platinum)

**ADEME, Luc Bondineau. Prestataires : SPHERA, Cécile Querleu, Alexander Stoffregen, ; GINGKO 21, Hélène Teulon, Analyse du Cycle de Vie relative à l'Hydrogène – Production d'Hydrogène et Usage en Mobilité Légère, Septembre 2020*

→ FCEV improvements expected

Lightweighting

- Less materials
- Less processing / energy for manufacturing
- Reduce energy consumption .
  (today FCEV 16% heavier vs Diesel)

Reduce use of materials with high environmental impacts

- Carbon fibers
- Lithium and cobalt for batteries
- Platinum for FC

Increase equipment's durability / lifespan

- 300 000 km vs 200 000 km
  =1/3 less abiotic resources

Recycle

- Decrease abiotic resource impact by 50% (platinum and carbon fiber)

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