RECYCLING COMPOSITE TECHNOLOGIES - RESINS, PROCESSES & NEW DEVELOPMENTS

CO-HOSTED BY:

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Composites Knowledge Network

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nasampe.org

YOUR HOST

Nick Bigeau
CTO/Founder at Resolve Composites,
Inventor of ReceTT

nickbigeau@resolvecomposites.com

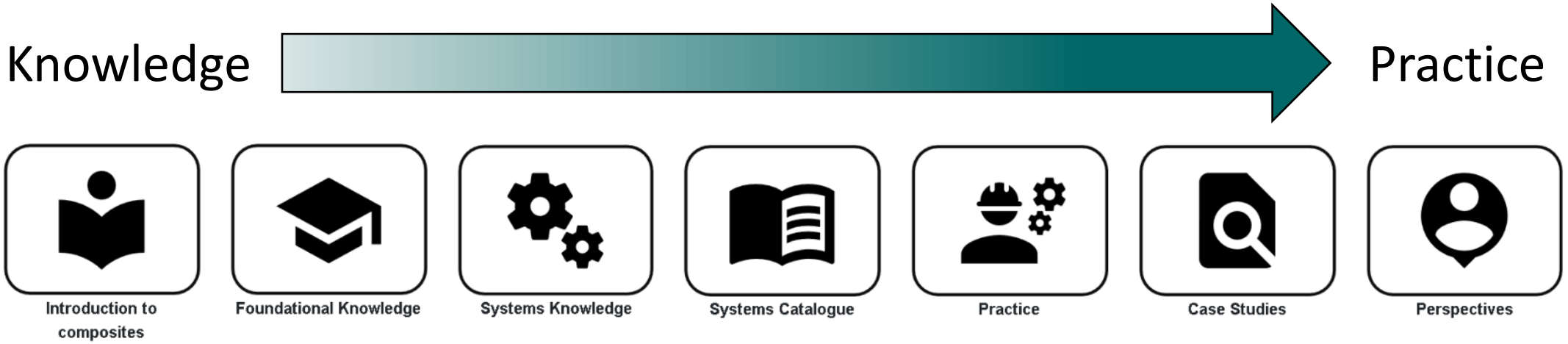
Nick's 15 years expertise in boatbuilding and aerospace has laid the foundation of Resolve Composites. Inventing a novel recycling method for composite materials – ReceTT.

KNOWLEDGE IN PRACTICE CENTRE (KPC)

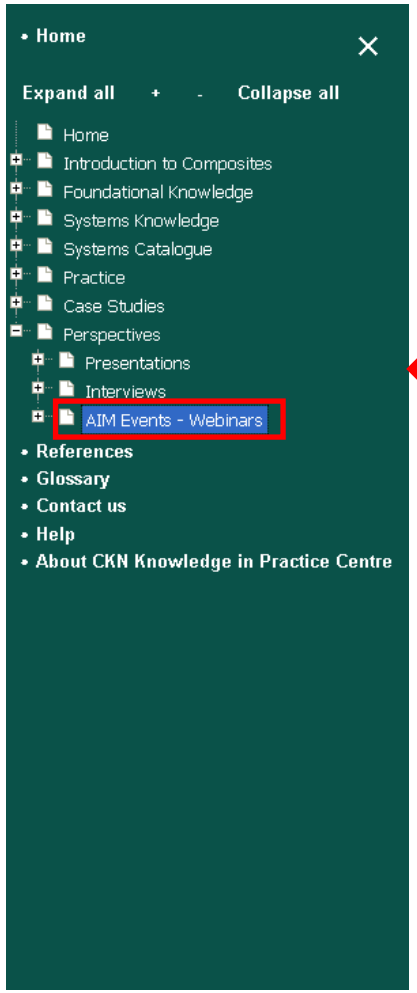
- A freely available online resource for composite materials engineering:

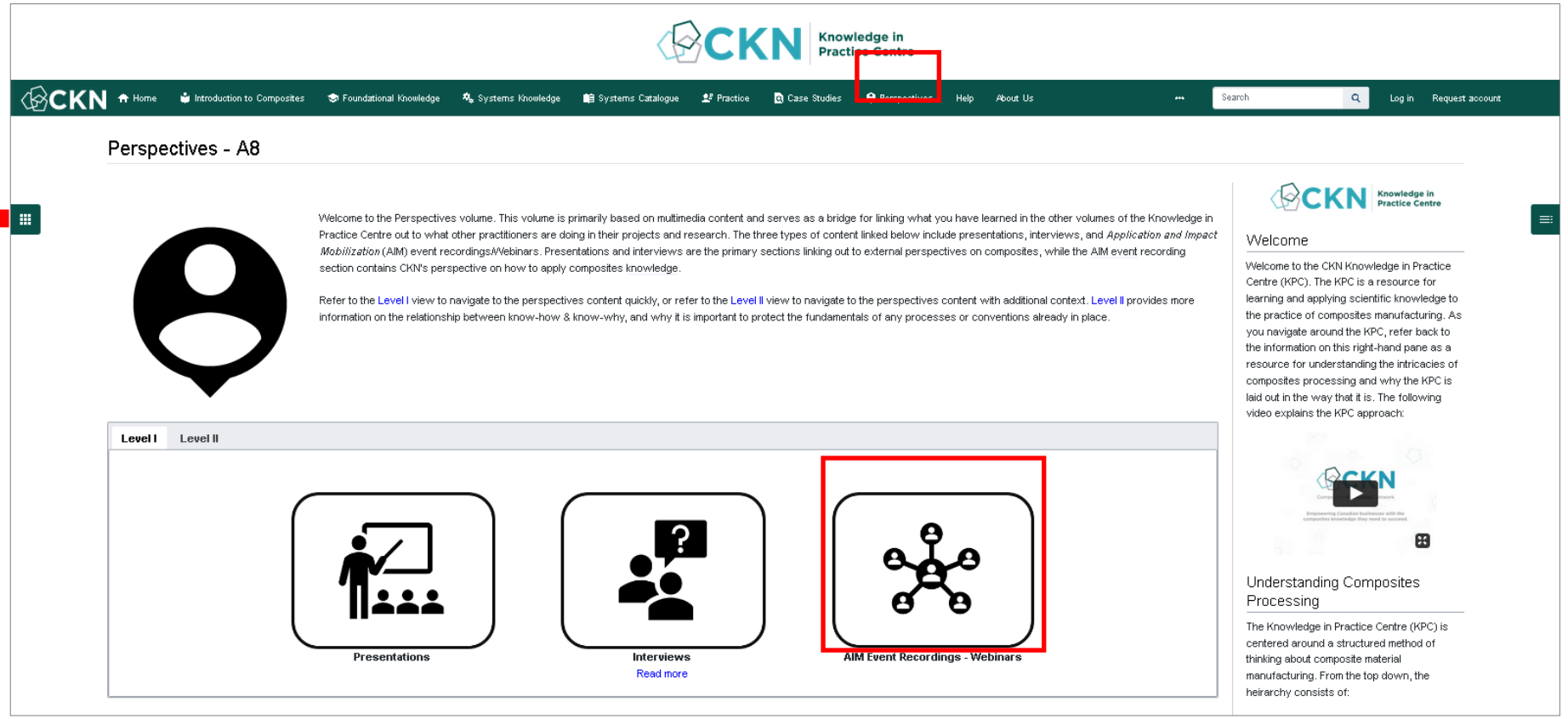
compositeskn.org/KPC

- Focus on practice, guided by foundational knowledge and a systems-based approach to thinking about composites manufacturing



PAST WEBINAR RECORDINGS AVAILABLE





Today's Webinar will be posted at:
https://compositeskn.org/KPC/A380

TODAY'S TOPIC:

Recycling Composite Technologies – Resins, Processes & New Developments

RECYCLING - AN INNOVATIVE APPROACH TO WASTE

INCINERATION

CO-PROCESSING

MECHANICAL

PYROLYSIS

SOLVOLYSIS

REPURPOSING

Click photos for reference cases

CKN Webinar A339 - Dr. Adam W. Smith - An Introduction to Composite Sustainability

COMPOSITE RECYCLING IN THE ARCHIVES

Wolfgang Unger, the inventor of Seacast™ back in **1984** & recycling of FRP & Carbon Fiber in **1973**.

Designed and sold chopper gun and tooling for direct repurposing of manufactured scrap.

Video link

Product used in Corvette

Canadian breaks code to recycle glass fibre

Every carmaker is bragging these days that its plastic parts are coded, meaning their composition can be identified by present and future recyclers.

The problem remains: where is all this recycled stuff going to go? As BMW points out, turning plastic fenders into plastic flowerpots isn't really recycling. Until you can make fenders into fenders, you're just delaying the inevitable trip to the landfill.

So it was a pleasant surprise that one of the press releases surrounding the 1993 Chevrolet Corvette said that some of its internal components would be made chanical process for separating the glass fibre strands from the "fillers" and bonding resins, rather than using heat or chemical processes, both of which pose environmental problems of their own.

The only procedure previously available for recycling glass fibre was to grind the whole part into a pulp, which could then be used to replace virgin filler in the glass fibre mix.

But as Phoenix vice-president for marketing, Randy Bastarache, puts it, "You're then competing with calcium carbonate — essentially, clean dirt — which you can "Our first step in this regard will be to make 'bulk moulded compound' pieces, like headlamp surrounds, using recycled strands as well as filler. The eventual goal for us and the moulders is make class A parts using up to 20 per cent recycled strands and filler.

"We can then achieve a cost reduction of from 10 to 15 per cent, as well as helping meet the environmental objective of truly making new fenders from old ones."

Phoenix's corporate progress was very rapid. A pilot program to ensure it is clean — no metals no contamination — and to en sure that the correct coded part are all placed in the same "box" because different plastics requir different treatment.

Recycled glass fibre can also b used in a variety of other proc ucts, such as bathroom sinks. Bu the auto industry has been th big supporter of the effort, sinc it is using lightweight and rust free glass fibre materials in ever increasing amounts.

"The co-operation from th panel makers and the carmaker has been outstanding," says Ba

In Autumn **1991**, Canadian company - Phoenix Fiberglass was operating a pilot plant and processing up to 1 tonne of recycled fiberglass per hour.

*Ford & GM were using their recycled fiberglass in the interior panels in the **1993** Chevrolet Corvette.*

Document link

In **2009** a pilot project to dispose of large wind turbines led to a €6 million investment for the construction of an industrial scale composite recycling plant with a capacity to recycle 60,000 tonnes/year.

Article link

MOTIVATION FOR IMPROVEMENT

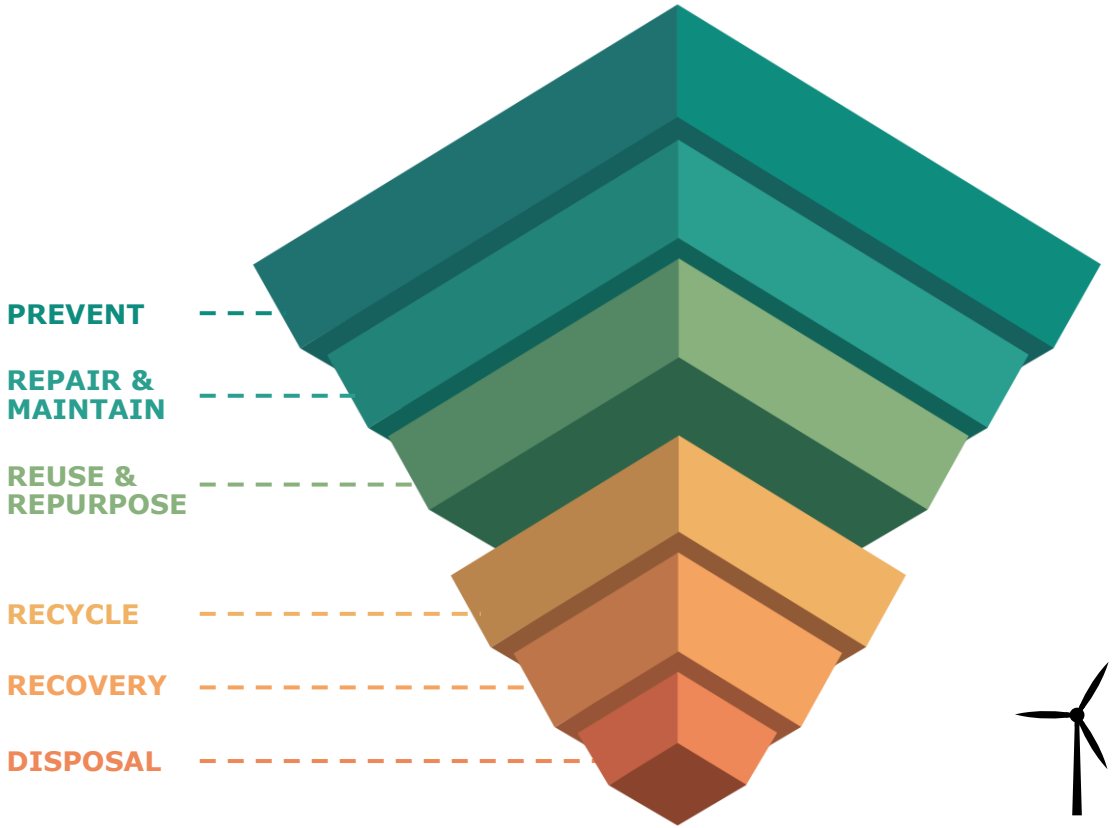
CURRENT MOTIVATION

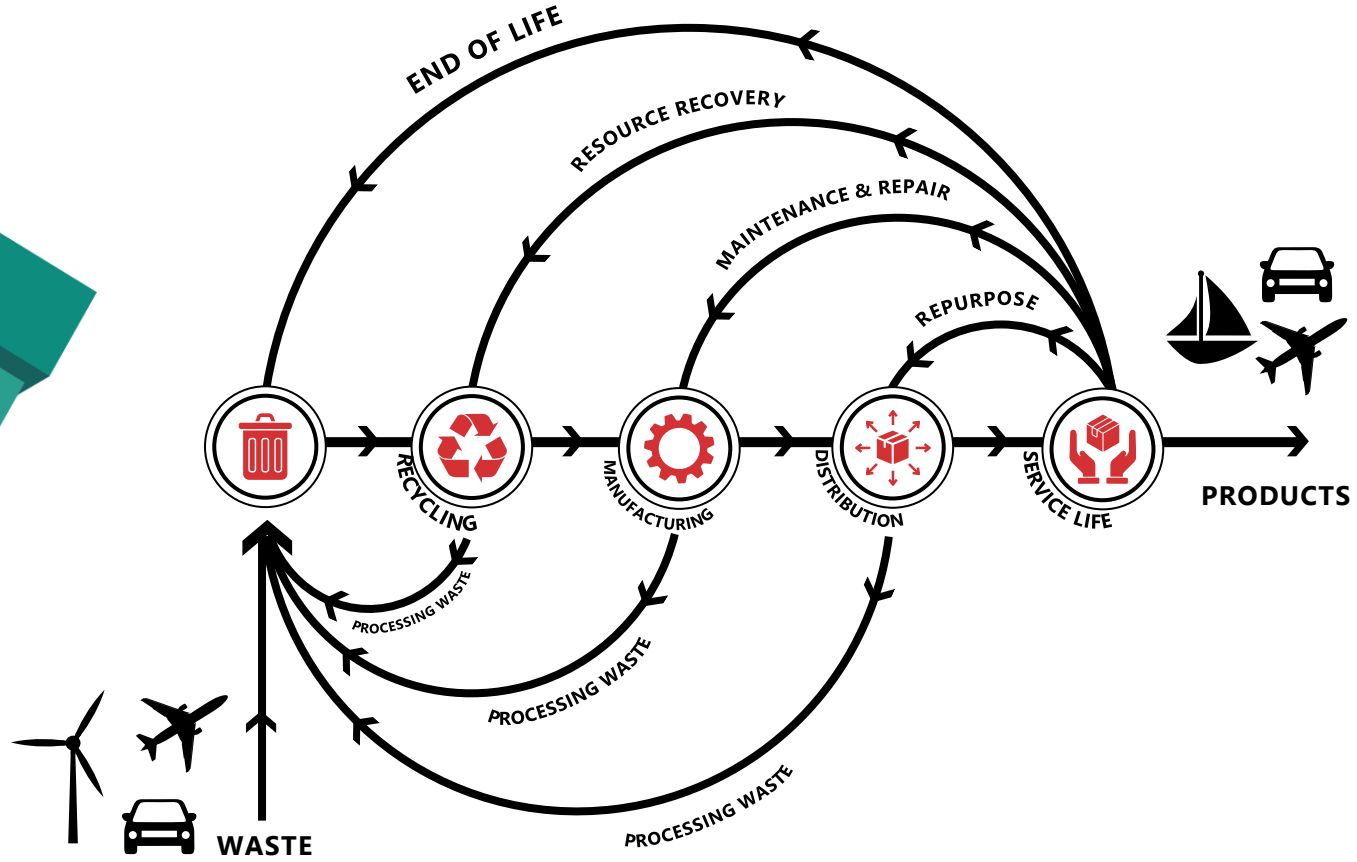
- More expensive than manufacturing – *virgin material cost lower compared to recycled fibers with current processing costs*
- Processing capacity – *unpredictable volumes*
- Legislation – *landfill bans, cross-border waste transportation, carbon footprint, recycled content*

ANTICIPATED MOTIVATION

- New Legislation - *in Europe & beyond*
- Raw material supply is unpredictable - *companies and Countries are looking to be self-sufficient as a result*
- Geo-political climate changing - *daily*

LINEAR VS CIRCULAR RECYCLING





[European Composites Industry Association – Knowledge Hub]

RECYCLABLE RESIN & SOLVENT TECHNOLGIES

RECYCLABLE RESINS

- Swancor's EzCyclo
- Aditya Birla's Recyclamine
- Arkema's Elium
- Mallinda's Vitrimax

How to Repair the Next Generation of Wind Turbine Blades

Wind blades circularity - Resins development for improved sustainability

Recyclable resins were designed to cleanly separate post cured materials, in some instances the resins can be recovered and/or reused.

NOVEL SOLVENTS

- Focus on specific polymers,
- Effective at lower temperatures,
- Effective at low ambient pressure,
- Less volatile and harsh,
- Accessible & economical
- Ionic Liquids

  More information here

Advancements in novel solvent technologies benefit all resins and thermosets – not just recyclable resins!

THERMOSETS

- Epoxies;

  Amine-cured

  Anhydride

  More information here
- Unsaturated Polyesters

  More information here
- Vinyl Esters

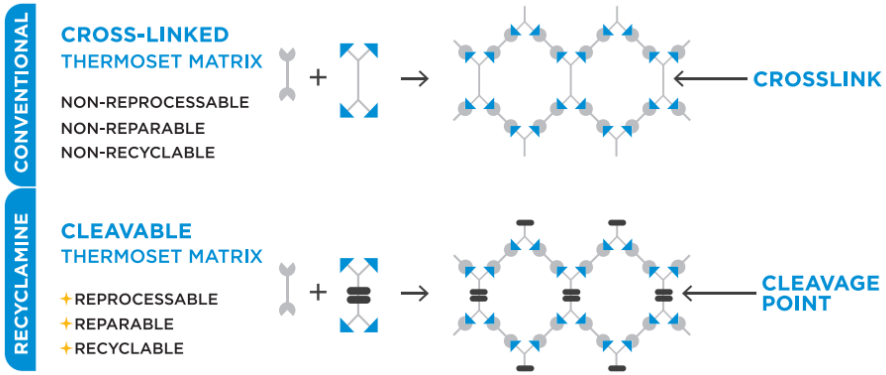
  More information here

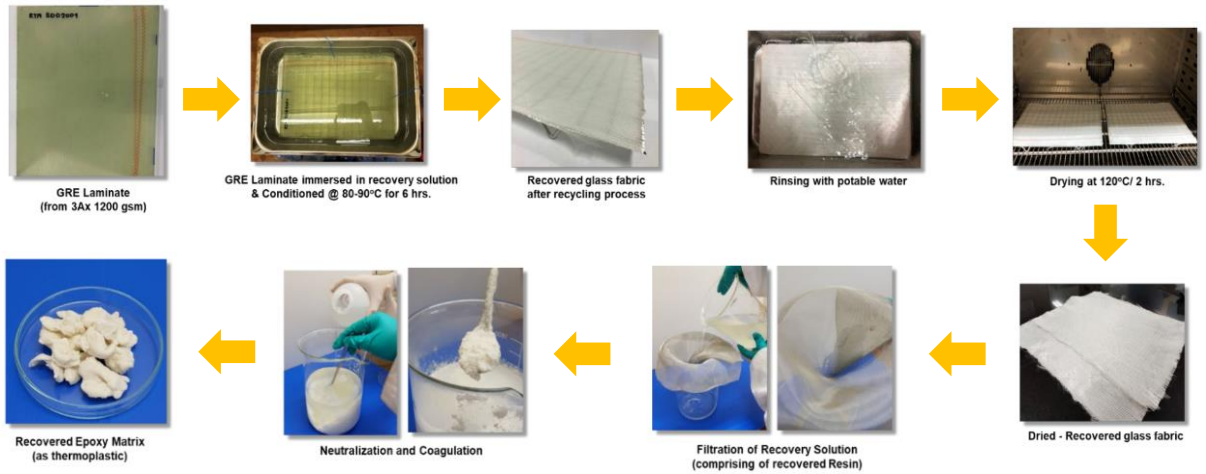
Traditional (or legacy) resins are difficult to recycle and require novel solvent technologies to separate cured composite components.

ADITYA BIRLA'S RECYCLAMINE

www.recyclamine.com

Recyclamine® is a platform chemistry with multiple unique Amine-based Curing Agents containing specifically engineered cleavage points at cross-linking sites, which, under pre-defined conditions, convert thermosetting epoxies into thermoplastics. This enables recovery and reuse of reinforcing fibre and matrix material.





The laminate was trimmed and subjected to solvolysis by immersing in recovery solution and conditioned at 80°C for 6 hours to enable cleavage of the recyclable epoxy matrix and its dissolution in the recovery solution. The glass fabric reinforcement of the composite, recovered from the recycling process was rinsed and dried. Recovery solution containing the dissolved epoxy matrix was filtered, neutralized and coagulated to recover the epoxy matrix as thermoplastic.

Recyclable epoxy systems for rotor blades

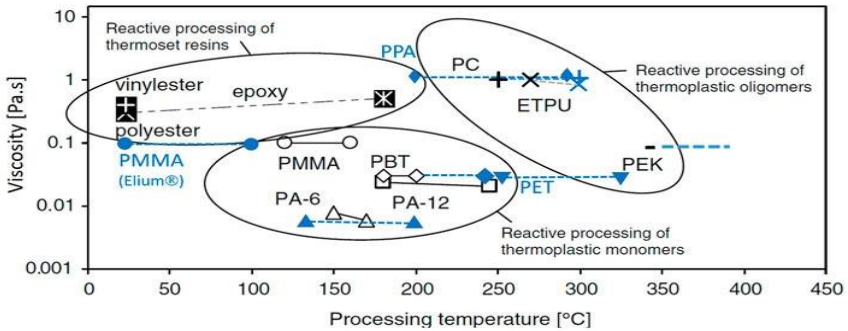
USEFUL RESOURCES

- Chemical Recycling of Fully Recyclable Bio-Epoxy Matrices and Reuse Strategies: A Cradle-to-Cradle Approach
- Full Recycling and Re-Use of Bio-Based Epoxy Thermosets: Chemical and Thermomechanical Characterization of the Recycled Matrices
- Innovative Chemical Process for Recycling Thermosets Cured with Recyclamines® by Converting Bio-Epoxy Composites in Reusable Thermoplastic—An LCA Study
- Recyclamine® - novel amine building blocks for a sustainable world

ARKEMA'S ELIUM

www.arkema.com

Arkema (Paris, France) Elium® acrylic resin is claimed as the first thermoplastic resin compatible with RTM/infusion manufacture producing composite structures with mechanical properties similar to thermosets. The viscosity and processing temperature of Elium® resin are as low as 100 mPas and 20°C (ambient), respectively. Elium® resin is widely researched for thermoplastic composites via RTM/infusion, with use increasing due to the desirable characteristics above.



LINK - Monomer Selection for In Situ Polymerization Infusion Manufacture of Natural-Fiber Reinforced Thermoplastic-Matrix Marine Composites

USEFUL RESOURCES

- First pilot project of recycling PMMA - Risk Analysis on PMMA Recycling Economics
- Fatigue behavior of Elium® -based thermoplastic composites fabricated by liquid composite molding : A review
- Evolution of Physical, Thermal, and Mechanical Properties of Poly(methyl Methacrylate)-Based Elium Thermoplastic Polymer During Polymerization
- Structural validation of a thermoplastic composite wind turbine blade with comparison to a thermoset composite blade

- **Mixed Production Wastes** – *Elium Resin & Bostik adhesive waste from production*
- **Mix Composites Wastes** – *End of life products containing Elium Composites & Bostik adhesives.*
- **Sorted Production Wastes** – *Production waste after shredding separation and treatment by Suez*
- **Sorted Composites Wastes** – *Composites waste after shredding separation and treatment by Suez*

MECHANICAL RECYCLING

- **Recycled Compounds** – *Compound for 3D Printing, injection, compression*

CHEMICAL RECYCLING

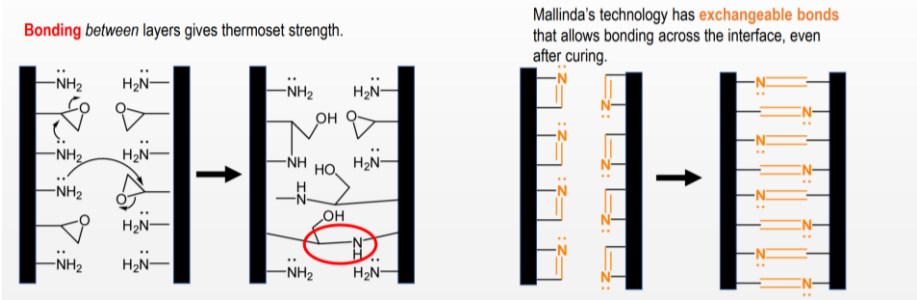
- **Raw and Pure Recycled Fibers** – *pure dry fiber after pyrolysis.*
- **Raw Recycled Monomer** – *raw monomer from thermal depolymerization*
- **Pure Recycled Monomer** – *ready to use monomer for production*

MALLINDA'S VITRIMAX

www.mallinda.com

The highly crosslinked nature of vitrimers means they exhibit similar mechanical properties to thermoset composites. However, vitrimer composites can be reprocessed after cure. This means that in-mold dwell times can be reduced significantly when compression forming pre-cured vitrimer composites.

THERMOSETS **VITRIMAX**



CLICK PHOTOS FOR MALLINDA'S YOUTUBE VIDEOS

USEFUL RESOURCES

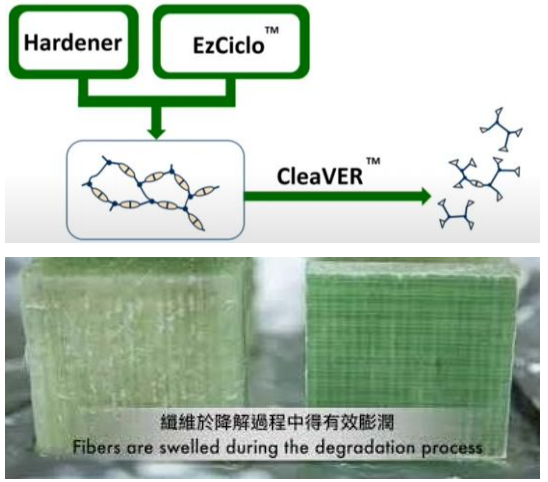
- Ludwick Leibler, Inventor of Vitrimers - From glass to Vitrimers : A Story of Exchangeable Links
- Vitrimer composites: current status and future challenges
- Carbon material/vitrimer composites: Towards sustainable, functional, and high-performance crosslinked polymeric materials
- Environmental Sustainability of vitrimer-based composite materials

Monomers used to make the polymer, can break down the polymer under certain conditions. Solubilized resin can be reused with no loss in mechanical performance, fibers have no residual resin and are ready for reuse. When mechanically processed at end of life, chemical bond exchange remains active, allowing surface welding of fine particles back to resin with matching mechanical performance. Vitrimer - containing composites can be mechanically processed and simply pressed into a new product.

SWANCOR'S EZCYCLO

www.swancor.com.cn

EzCiclo is a recyclable thermosetting epoxy resin, fiber reinforced composite made with EzCiclo resin can be recycled and degraded through CleaVER technology. CleaVER can turn waste composites into reclaimed glass/carbon fibers and oligomers. The recycled fibers and oligomers can be reused to produce composites which result in a close loop. The recycling process does not generate waste solvents and pollution. It can be applied across a range of industries including wind, sporting goods and automotive.



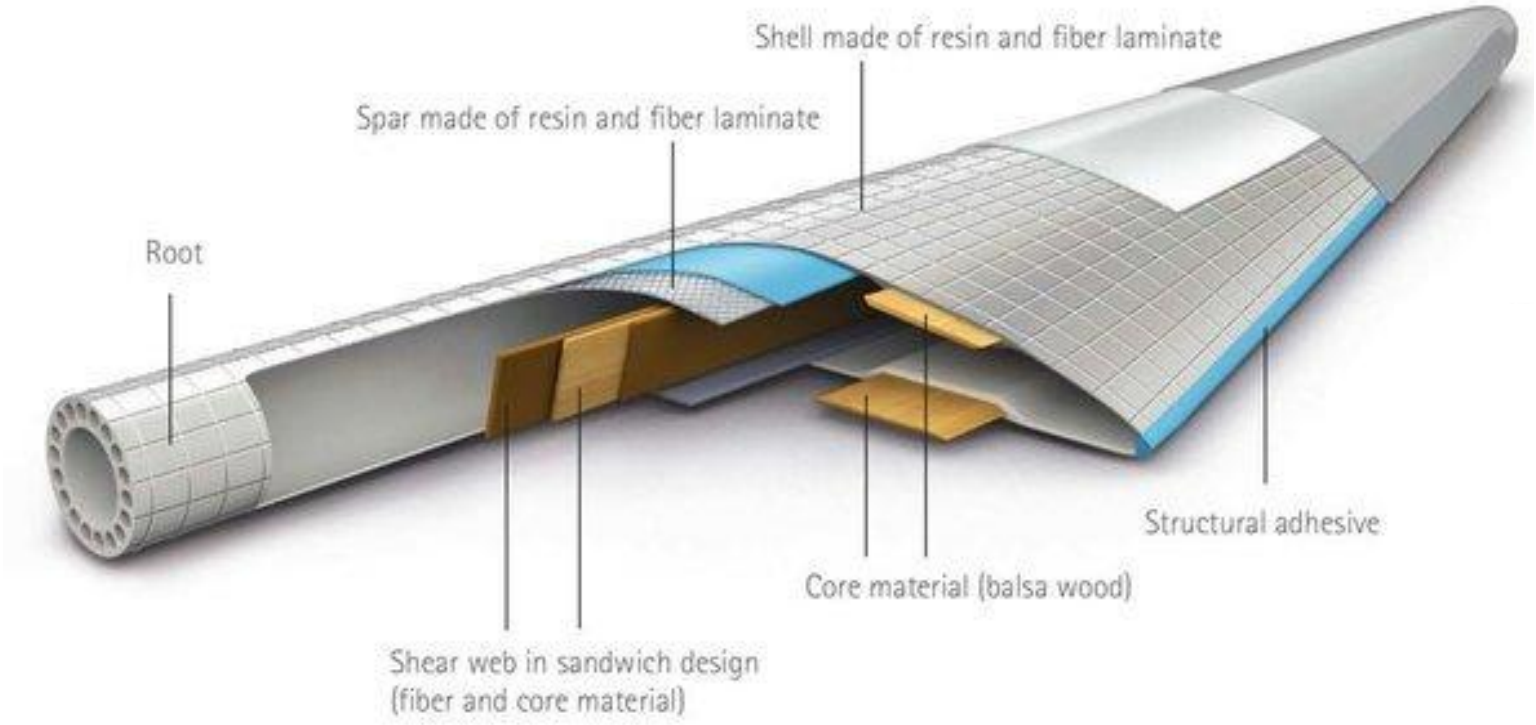
Utilizing CleaVER technology, end-of-life composites undergo a transformative process. Fibers are separated from resins, paving the way for their reuse into new applications. The resin is recycled into an oligomer which is then used to produce the corresponding resin again. Before the actual degradation process, the FRP must be cut into smaller pieces, so it can fit into the reactor and speed up the degradation process.

Source – Bjorn-Thorsen *(Distributor)*

USEFUL RESOURCES

- Composites Exchange - Swancor recyclable thermosetting epoxy resin "EzCiclo" and "CleaVER"
- Composites World - Swancor launches recyclable thermosetting epoxy resin
- Swancor - Recyclable Radical-Cured Resin – RH Series
- PlastForum - Rethinking composite recycling with Swancor's innovative solutions

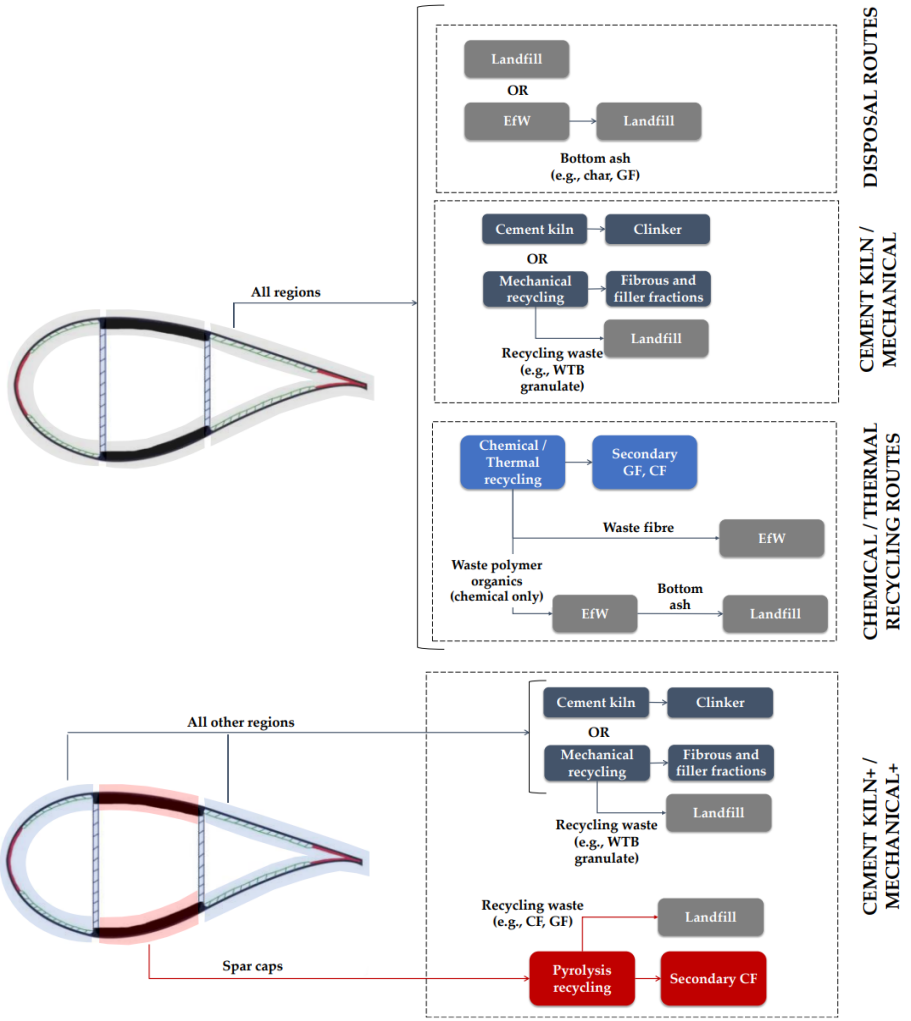
HOLISTIC MATERIAL CHOICES FOR SUSTAINABILITY

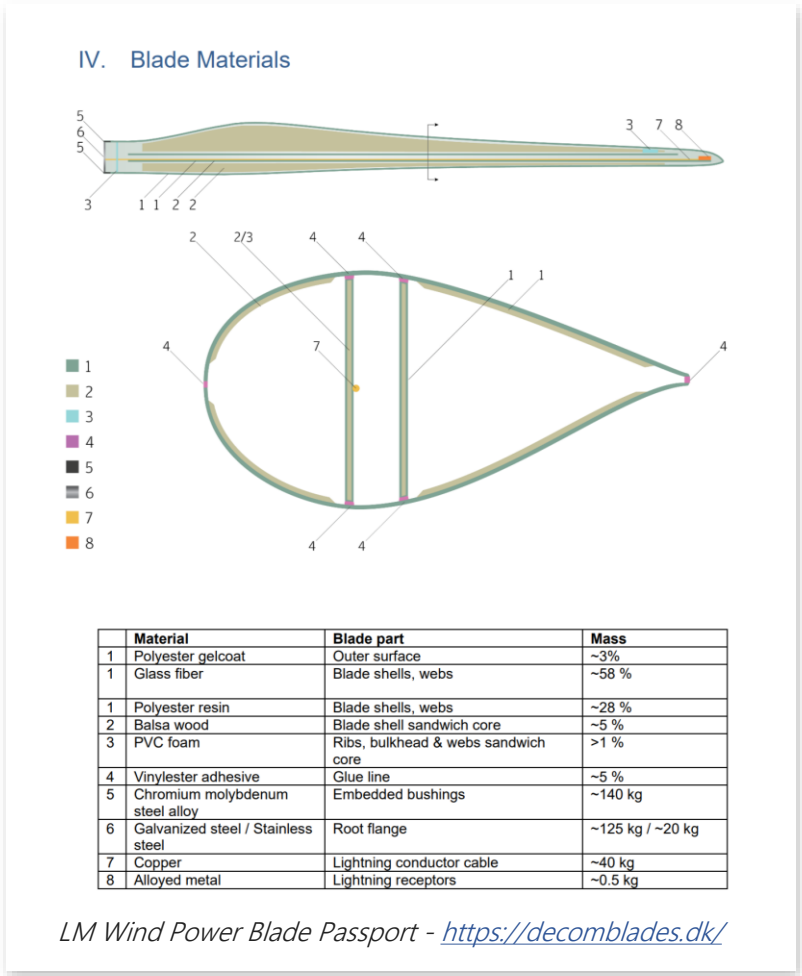


Research Gate - Assessment of Present & Future Decommissioned Wind Blade Fiber-Reinforced Composite Material_ in the United States

Schematic showing overview of process and material flow across wind blade EOL scenarios

MATERIAL PASSPORTS



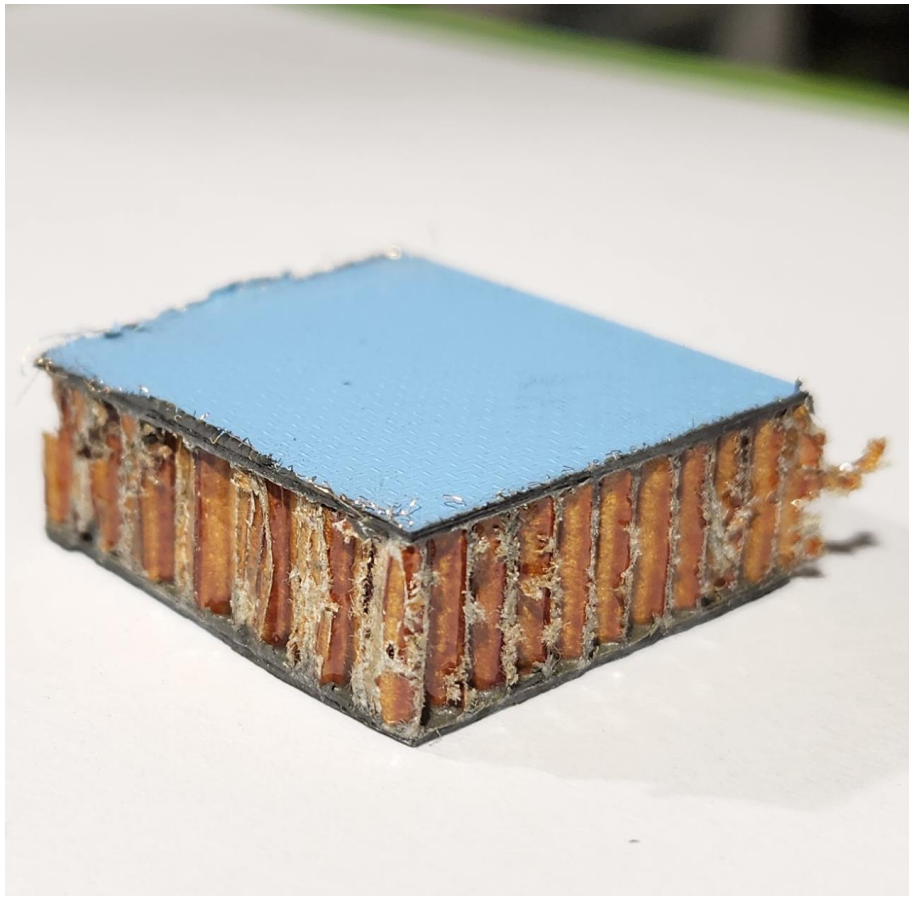


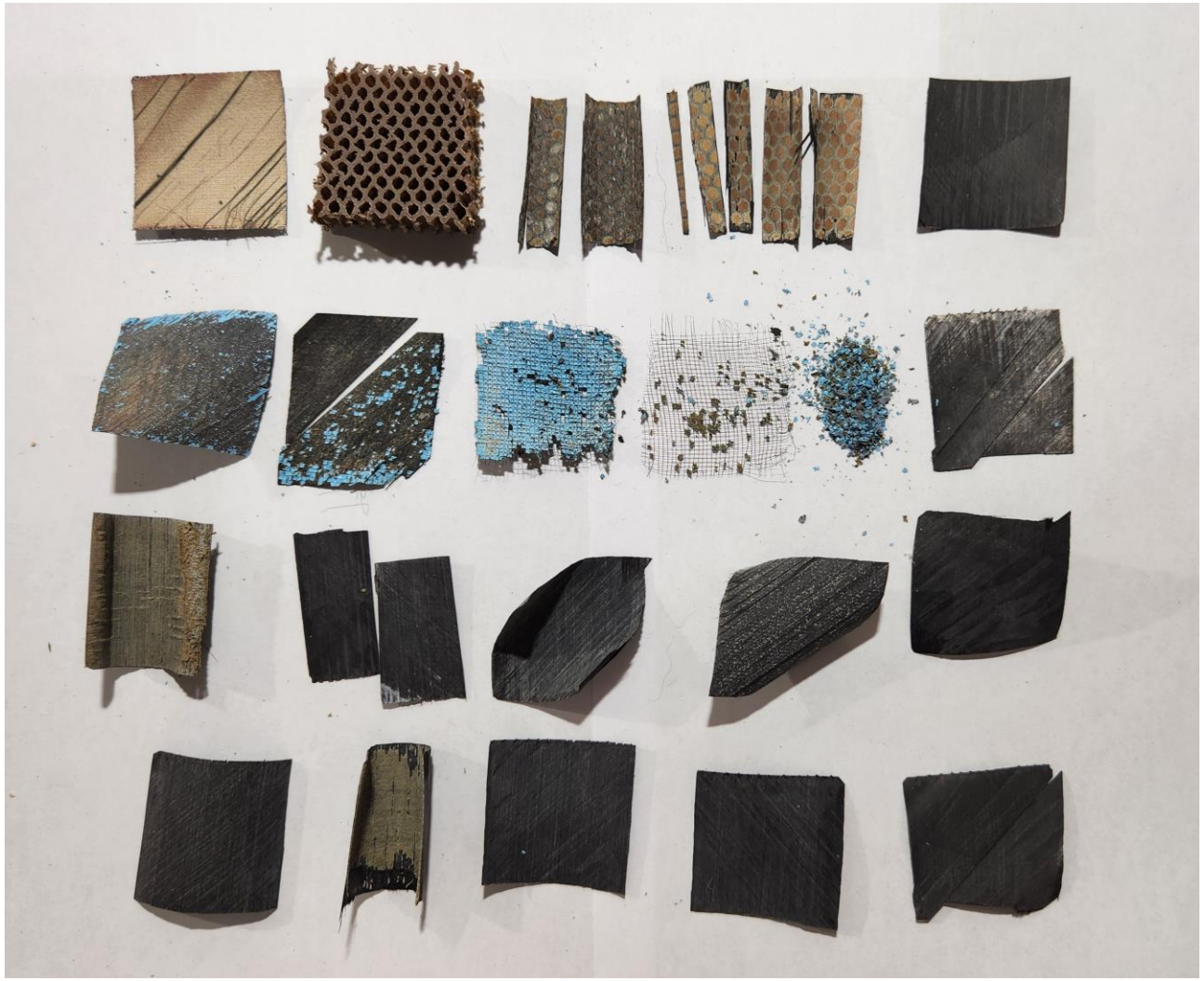
	Material	Blade part	Mass
1	Polyester gelcoat	Outer surface	~3%
1	Glass fiber	Blade shells, webs	~58 %
1	Polyester resin	Blade shells, webs	~28 %
2	Balsa wood	Blade shell sandwich core	~5 %
3	PVC foam	Ribs, bulkhead & webs sandwich core	>1 %
4	Vinylester adhesive	Glue line	~5 %
5	Chromium molybdenum steel alloy	Embedded bushings	~140 kg
6	Galvanized steel / Stainless steel	Root flange	~125 kg / ~20 kg
7	Copper	Lightning conductor cable	~40 kg
8	Alloyed metal	Lightning receptors	~0.5 kg

LM Wind Power Blade Passport - https://decomblades.dk/

[A strategic approach to wind turbine blade recycling: Using life cycle assessment to enable data driven decision making]

MATERIAL PASSPORTS - THE HIDDEN COMPLEXITY



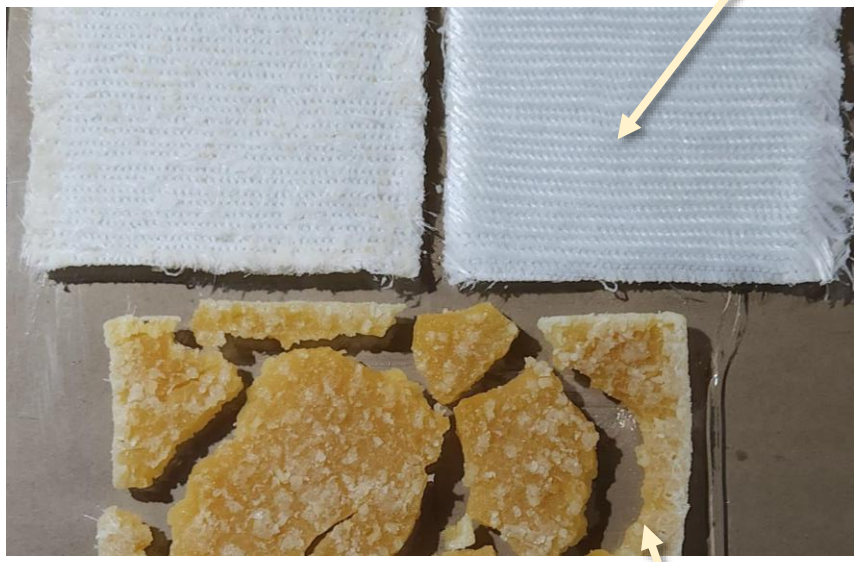


CONTAMINATION CHALLENGES IN RECYCLING - CASE STUDY #1

Infusion Consumable

Fiberglass Polyester-stitched

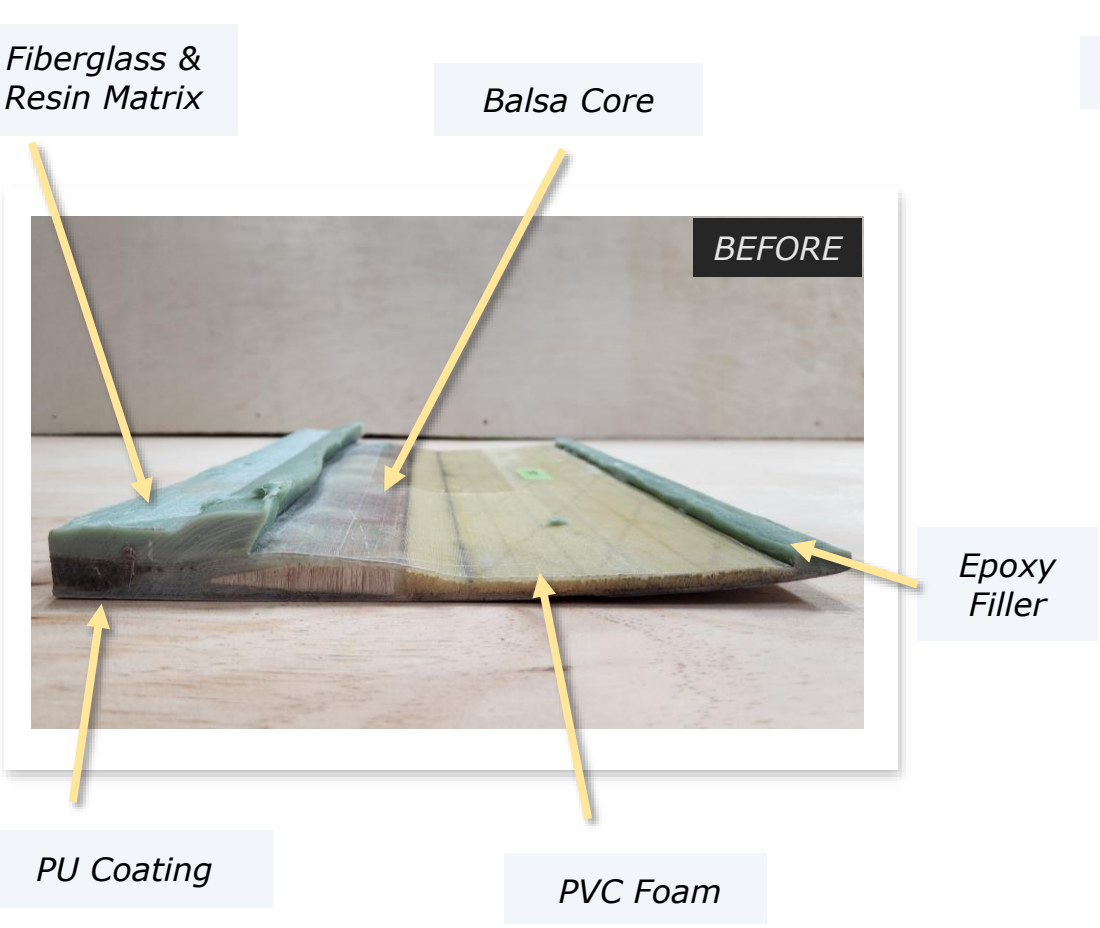
Fiberglass Nylon-stitched

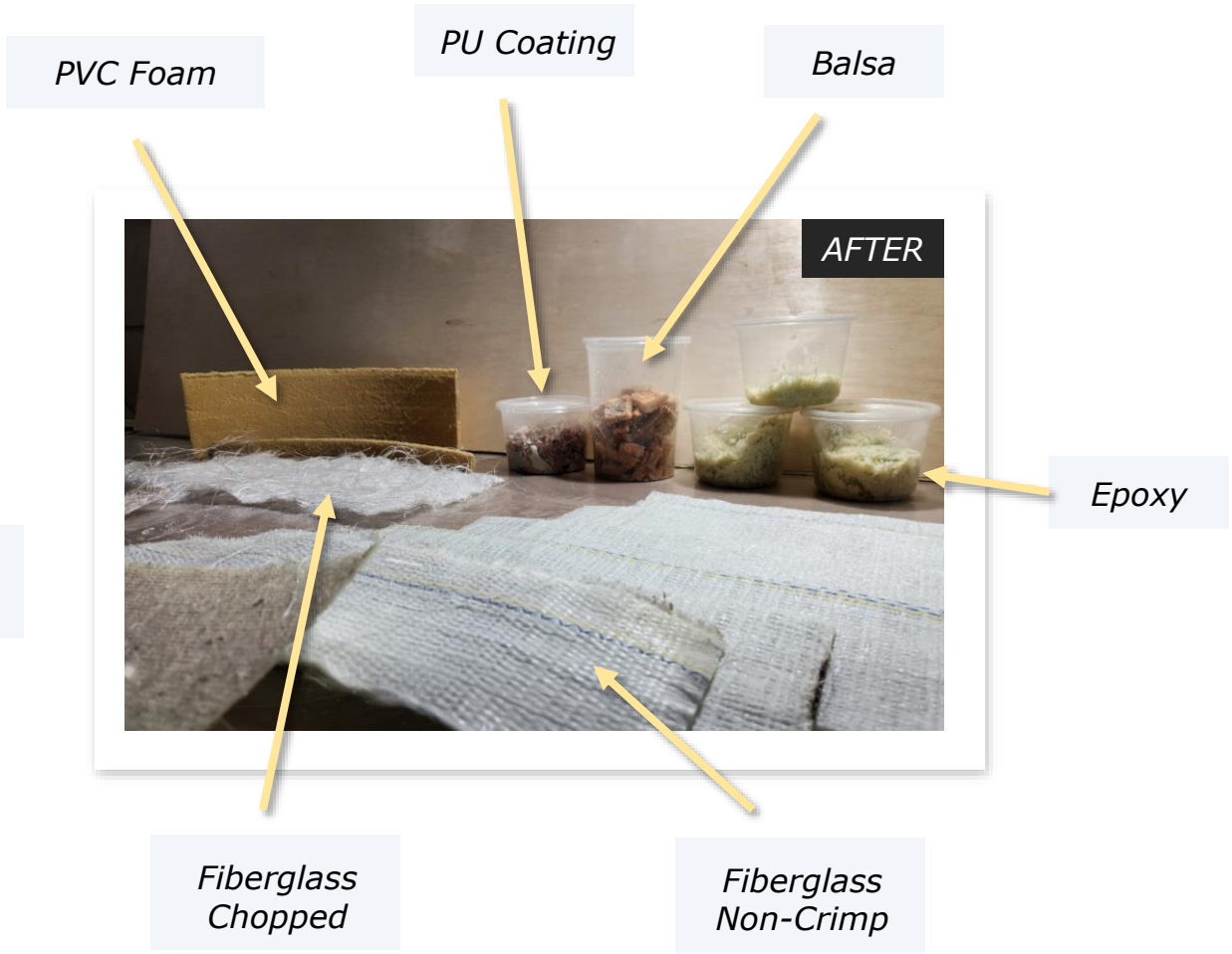


Styrene Acrylonitrile (SAN) foam

The Effect of Nylon and Kevlar Stitching on the Mode I Fracture of Carbon/Epoxy Composites

CONTAMINATION CHALLENGES IN RECYCLING - CASE STUDY #2

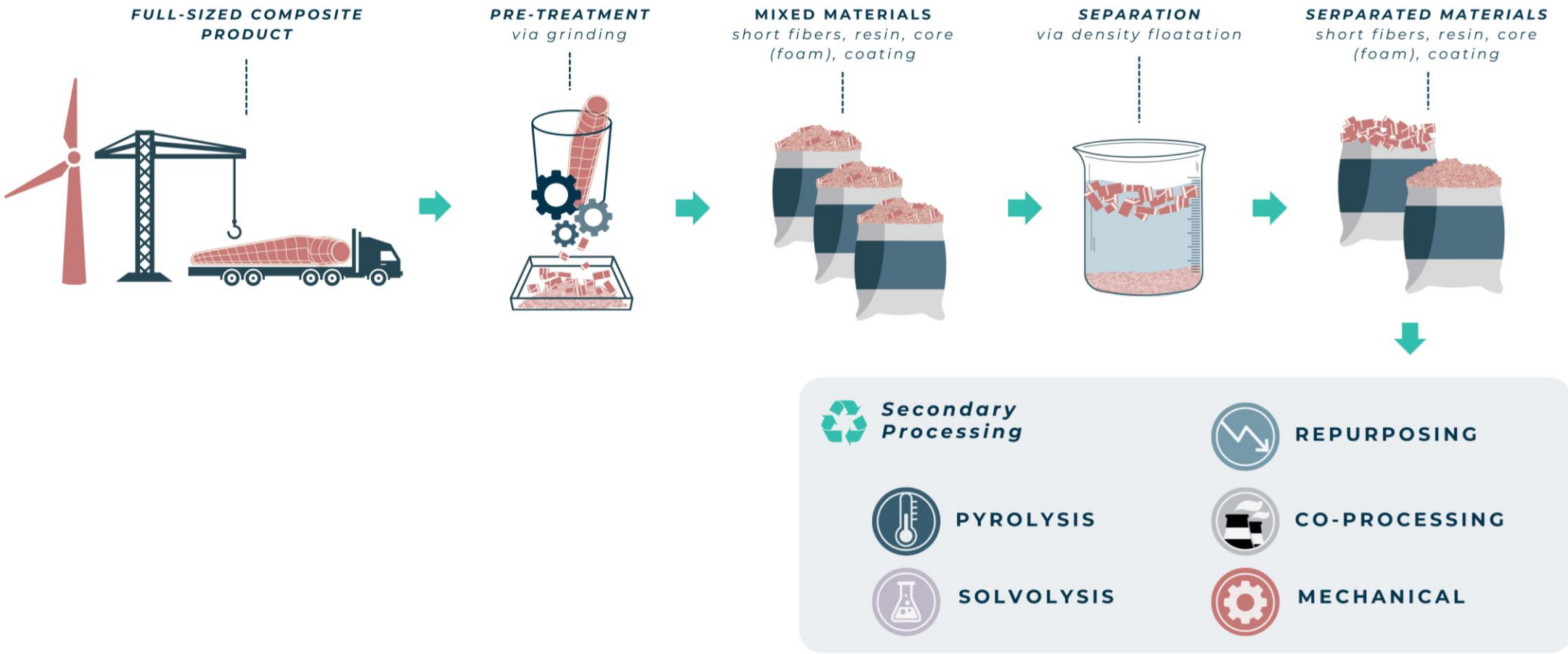




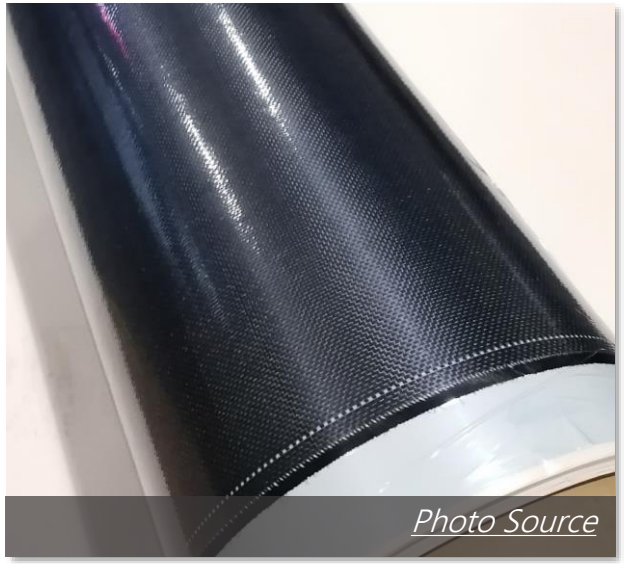
RECYCLING PROCESSES - KEEPING UP WITH INNOVATION

[Composites World - JEC World 2025 highlights: Evolving recycling and biomaterials technologies]

EXAMPLE OF PROCESSING A RECYCLABLE RESIN



SHORT FIBERS & MANUFACTURING WASTE



Uncured Prepregs

Cured Fibers

Dry Fibers

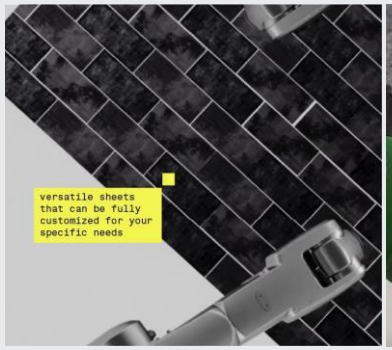
NOVEL APPROACHES FOR SHORT FIBER INTERMEDIATES

NON-WOVEN
www.verretex.com

www.composite-recycling.ch

MOBILE THERMOLYSIS TECHNOLOGY

CARBON CHIPS
www.fairmat.com



www.vartega.com

EASYFEED BUNDLE™

NON-CRIMP FABRIC
www.nova-carbon.com

www.lineat.co.uk

FIBER-ALIGNED TAPE

3D FILAMENT
www.fibecycle.com

www.geesrecycling.com

FIBER COMPOSITE PANELS

LONG FIBER RECOVERY

Aircraft Fuselage

8m-length x 4m-width

Carbon fibre-reinforced Thermoplastic polymer composites (CFRTP)

AIRBUS LINK

Wind Turbine Blade

81m-length

Unidirectional & Biax Glass Fibers, Carbon Fibers, Core & Recyclable Resin

SIEMENS GAMESA - LINK

Hydrogen Tank

-

Continuous Carbon Fiber Filament Winding & Thermoplastic Resin

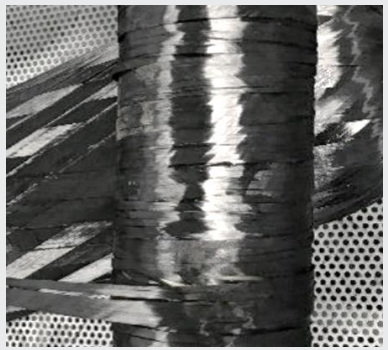
INSTITUT MINES-TÉLÉCOM - LINK

NEW APPROACHES FOR LONG FIBER INTERMEDIATES

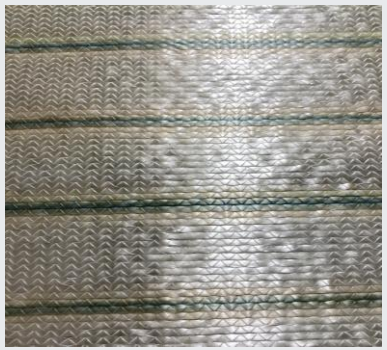
LONGWORTH

PRESSURE VESSEL – RECOVERED UNIDIRECTIONAL CARBON TOW

Post-processed Pressure vessel



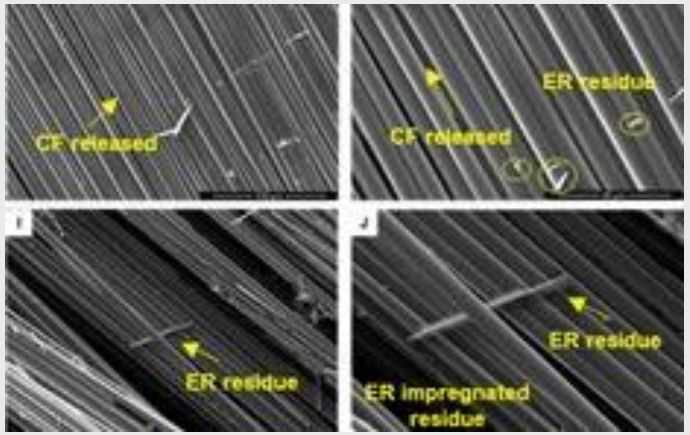
Re-manufactured Pressure vessel from recycled fibers



WIND TURBINE BLADE – RECOVERED UNIDIRECTIONAL FIBERGLASS

RESOLVE COMPOSITES

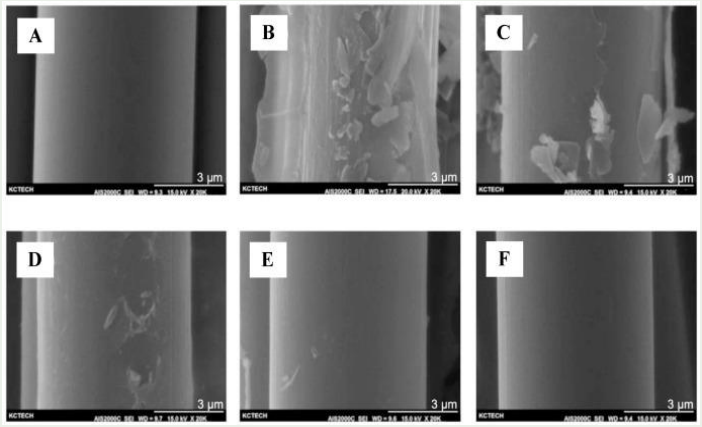
NEW APPROACHES TO COMPOSITE RECYCLING



MICROWAVE ASSISTED PYROLYSIS

https://pubs.acs.org/doi/10.1021/acssusresmgt.4c00201

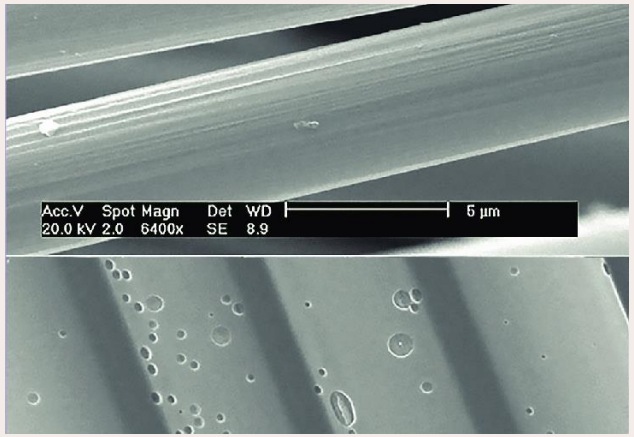
Thermal recycling using a microwave oven enabled the recovery of clean and intact CF without compromising its mechanical properties, facilitating its reuse in new applications and processing. Based on the results, thermal recycling using a microwave oven shows promise for CF recovery with low pyrolysis time, resulting in greater energy efficiency during thermal recycling.



SUPER-CRITICAL STEAM

https://doi.org/10.1016/j.jclepro.2023.139320

Superheated steam studies report recovering carbon fibres with retained tensile moduli of around 90%–100% and tensile strengths of 65%–100% when compared to virgin carbon fibres, however, when optimised it is shown that carbon fibres can be recovered with no loss in stiffness and strength.

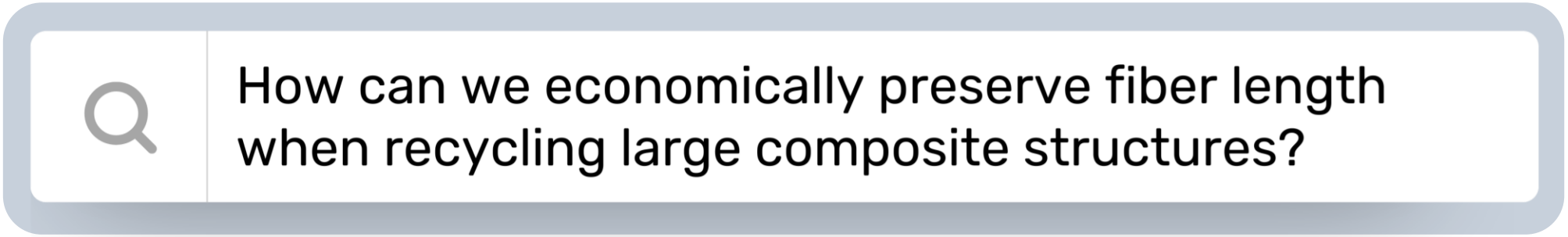


TEMP CONTROLLED PYROLYSIS

https://doi.org/10.1016/j.resconrec.2021.105482

In this work, the thermolysis recycling process is used to preserve the fibre structure including fabric stacking sequence, fibre orientation, alignment and length from the waste TS-CFRP parts. Investigation on the rCF structures with varying fabric and stacking sequence has been conducted to understand fibre nesting, alignment disturbance and permeability characteristics for composites remanufacturing.

QUESTION


How can we economically preserve fiber length when recycling large composite structures?

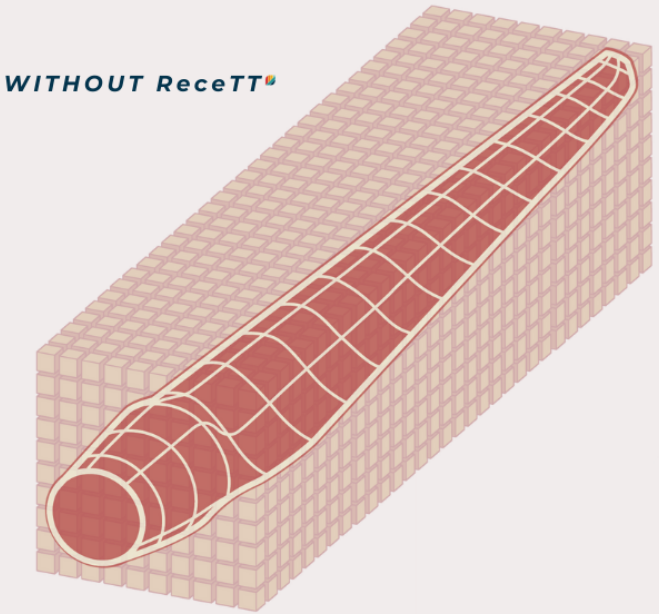
RESOLVE COMPOSITE TRANSFORMATION TECHNOLOGY

ReceTT
Resolve Composites Transformation Technology

RESOLVE COMPOSITES

WITHOUT AN IMMERSION TANK, WE CIRCULATE SOLVENT ACROSS JUST THE SURFACE AREA OF ANY SIZE COMPOSITE PART, EFFICIENTLY MINIMIZING THE VOLUME OF SOLVENT NEEDED FOR LARGE COMPLEX GEOMETRY.

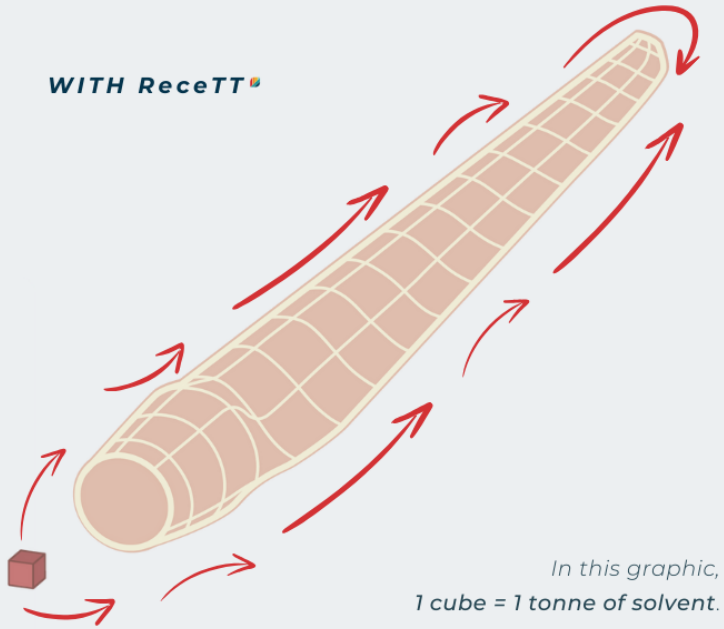
WITHOUT ReceTT



*Consider the challenge of recycling a **97 metre** wind turbine blade in a conventional tank or reactor. You would need about **3,200 tonnes** of solvent to perform this task.*

*In contrast, our technology enables us to achieve this same recovery with only **1 tonne** of solvent to recycle the entire blade.*

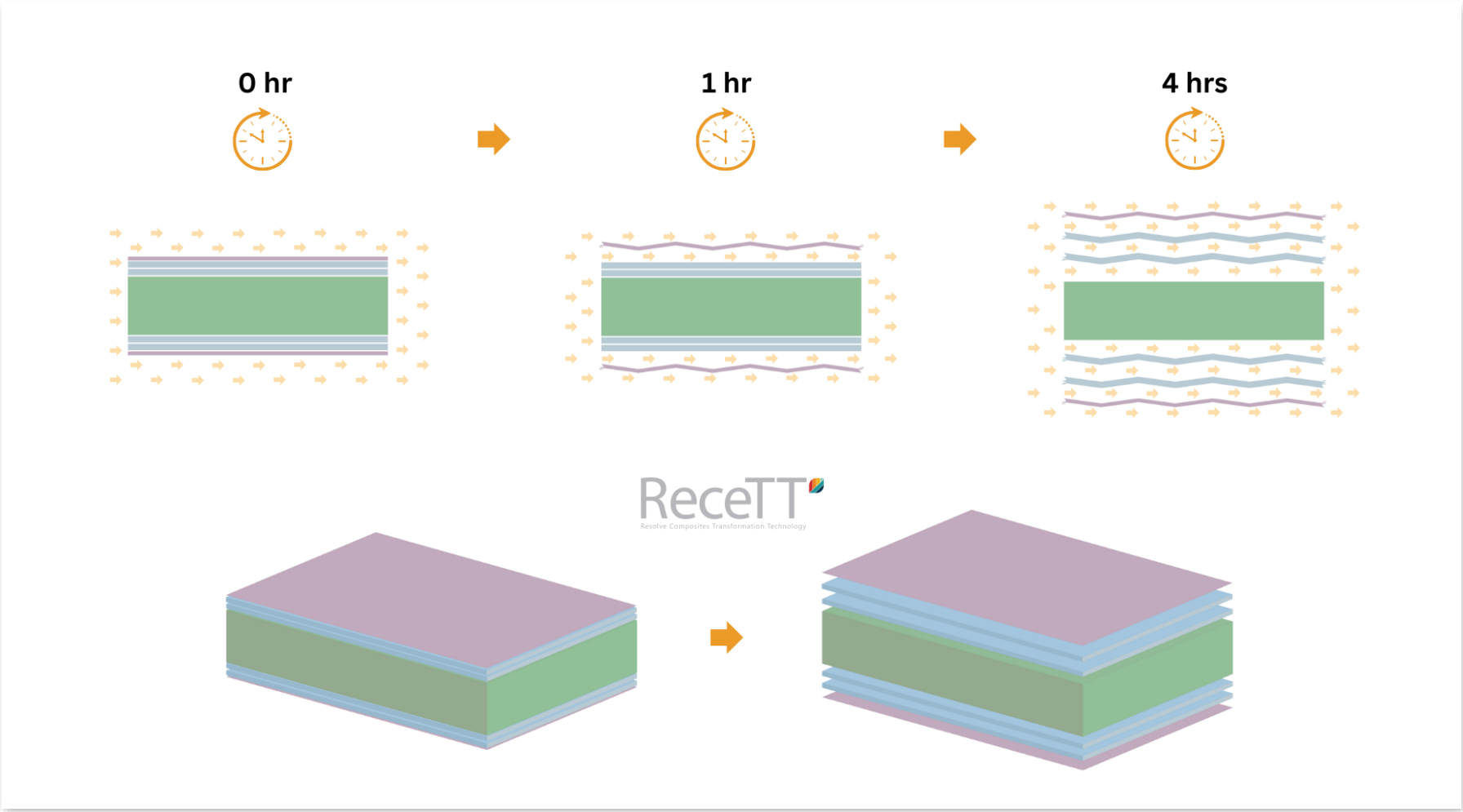
WITH ReceTT



In this graphic,
1 cube = 1 tonne of solvent.

[ReceTT is patented technology of Resolve Composites]

EROSION OF MATRIX BETWEEN LAYERS

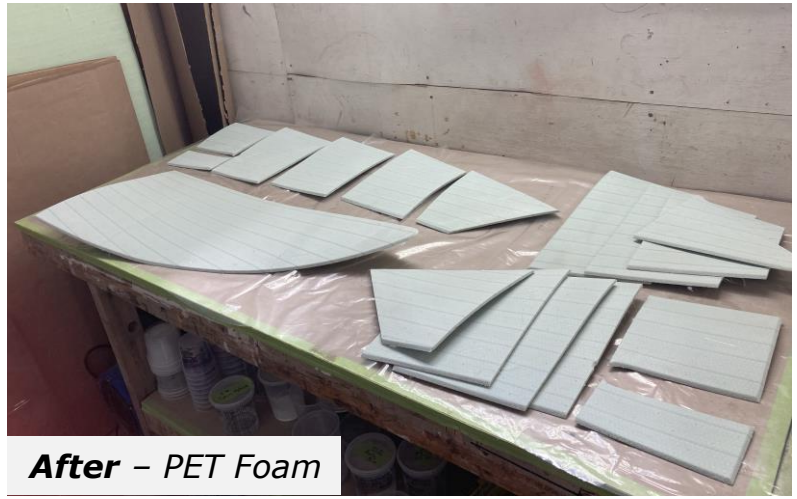


PROTOTYPE BOW SECTION

Before *– Full-sized bow section*

> *Our patented ReceTT Transformation Technology offers a novel and efficient approach to chemical recycling without using an immersion tank. Unlike traditional composite recycling processes which often create contaminated feed stock, ReceTT allows for a gentle separation of materials from full-sized composite products to occur before any required post-processing. ReceTT is keeping pace with emerging recyclable resin and solvent technologies, facilitating their full potential and reclaiming the value of materials from products that can be separated in their original form.*

After *- Fiberglass*



After *– PET Foam*

PROTOTYPE BOW SECTION - DATA

Resolve Composites Prototype Bow Section Data

COMPARISON OF SOLVENT USAGE - RECETT VS AN IMMERSION TANK

PROTOTYPE CONSTRUCTION

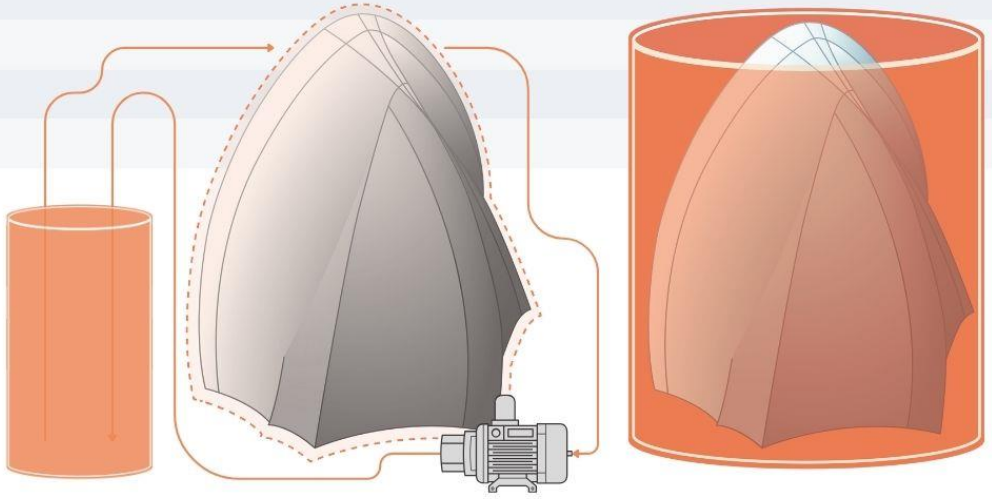
Fibreglass	4 Layers 17oz Biax +/-45
Resin System	Recyclamine®
Foam Core	1/4" Armacell Recycled PET
Total Resin	5.25 Kg
Total Weight	12.25 Kg

PROCESSING WITH RECETT

Weight of recovered Fibreglass	5.8 Kg
Weight of recovered Foam	1.2 Kg
Thermoplastic recovered	5.25 Kg
Water usage *(rinsing)*	46 L
Solvent usage *(25% Acetic Acid)*	**143.7 L**

Solvent usage breakdown

Solvent over surface area ***4x (700ml/SqM)***	***2.8 L***
Solvent in feed lines ***9x (70ml/m)***	***630 ml***
Volume of heating Tank ***R=46cm, H=84.5cm***	***140.27 L***



CALCULATION FOR IMMERSION TANK

Calculations are based on best estimates

Dimensions of Part	1.8m x 1m x 1.6m
Volume of Immersion Tank	1.4 Cubic Meters
Solvent usage	**1423 L**

BROUGHT TO YOU BY RESOLVE COMPOSITES

THE SECOND WIND PROJECT





THE SECOND WIND PROJECT

[YouTube - The Second Wind Project]

[Composites World - Resolve Composites, Siemens Gamesa partner in The Second Wind Project]

THE SECOND WIND PROJECT – COMPARATIVE TESTS

Comparative Mechanical Testing between virgin and recycled fiberglass

Identifying any property loss, considering sizing removal and fiber misalignment.

TESTS - Flexural, Tensile, Facesheet

RESULTS - Average property loss = 10%

Photo Credit & Testing – Composite Research Network

Resizing Approach to Increase the Viability of Recycled Fibre-Reinforced Composites

THE SECOND WIND PROJECT - DATA

Weight of Spar Cap	**254 Kg**
Dimensions of Spar Cap	**1m x 6m x 0.05m**
Weight of Fibreglass recovered	**170 Kg**
Longest Fibreglass sheet recovered	**5.8m**
Fiberglass Architecture - *maintained*	**Unidirectional, Biax +/- 45**
Percentage of recovered Fibreglass	**100%**
Resin system of Spar Cap	**Recyclamine®**
Solvent used for recovery	**25% Acetic Acid**

[The Second Wind Project - Resolve Composites]

KEY TAKEAWAYS FROM THE SECOND WIND PROJECT

IS NOW THE RIGHT TIME FOR RECETT?

Recyclable Resins;

Adoption

Service Life

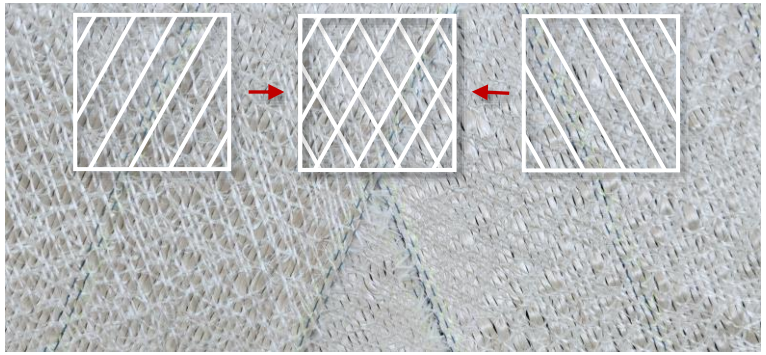
End of Life

REPURPOSING

Is direct repurposing realistic?

-

Can we repurpose thermoset materials?



LONG FIBERS

How long do they need to be?

-

Is it worth it?

KEY TAKEAWAYS FROM THE SECOND WIND PROJECT

Thermoset composite material processed with ReceTT

A UNIVERSAL APPROACH WITH RECETT

Can we process thermosets?

-

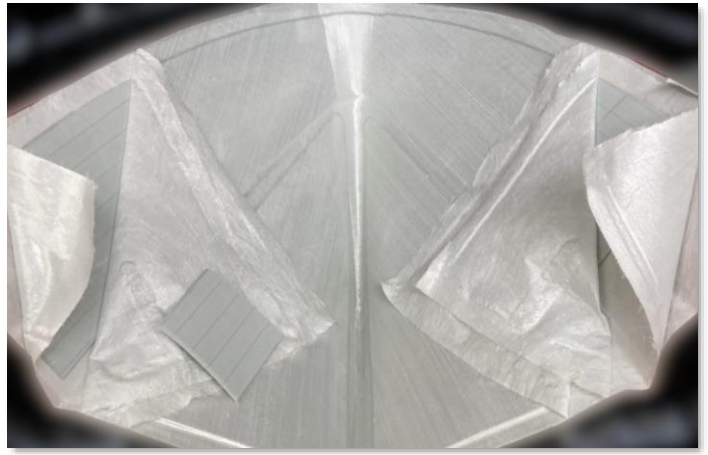
Can fiber length benefit current process?

-

Can we cross-over technologies?

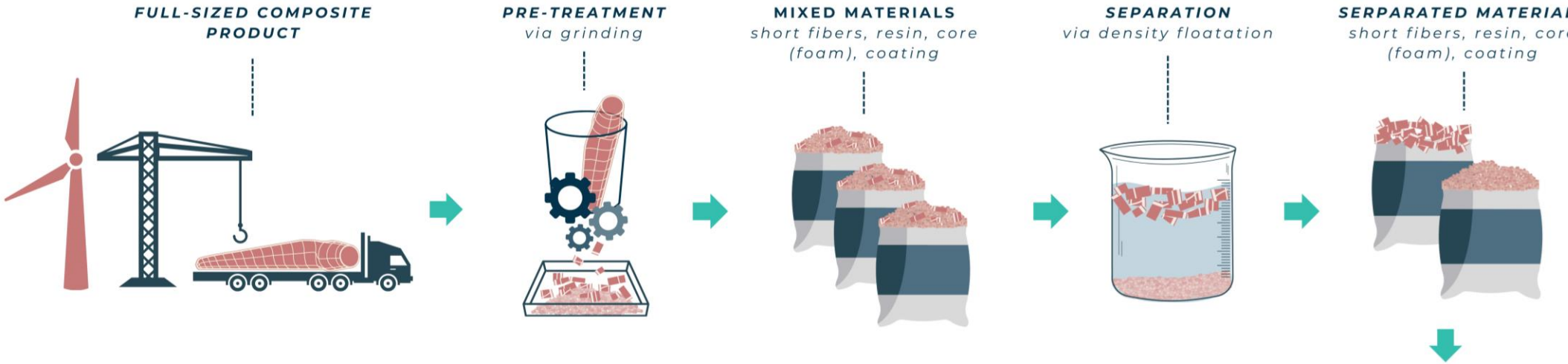
-

What compromises of expectations need to be made?

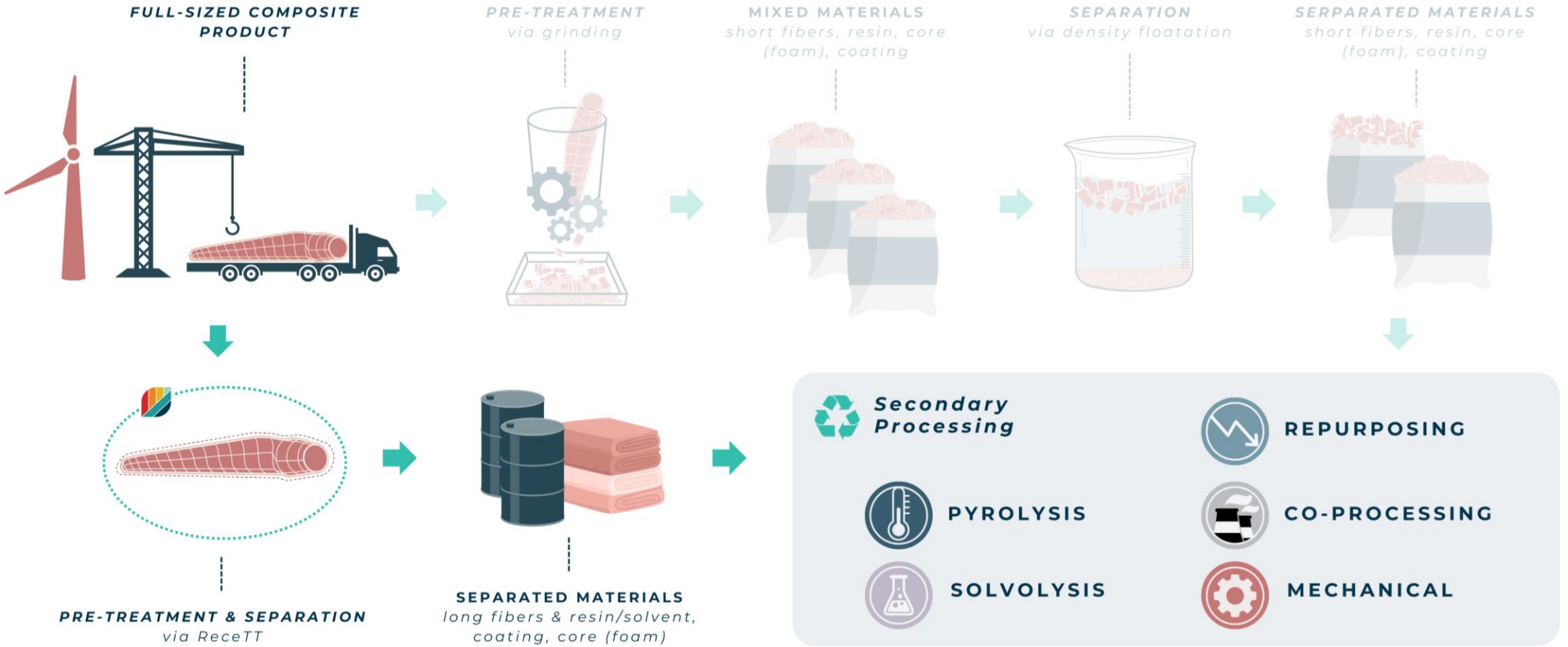


Recyclable resin bow section processed with ReceTT

RECYCLING WITH MECHANICAL PRE-TREATMENT



USING ReceTT FOR PRE-TREATMENT & SEPARATION



Thank you for joining us!

Keep an eye out for upcoming AIM events:

Introduction to Machining of Composite Materials
Hosted by Dr. Xiaoliang Jin
May 28, 2025
https://compositeskn.org/KPC/A383

And don't forget to visit the KPC for more information:

https://compositeskn.org/KPC

Today's Webinar will be posted at:
https://compositeskn.org/KPC/A380

PILOT PROJECTS TO BE ACKNOWLEDGED

HEALABLE RESINS

www.comppair.ch

The composite recycling project's goal was to close HealTech's recycling loop on a 3D monolithic product (shoe sole), representative of many sporting goods, and relevant to both companies' activities. The project was a big success and demonstrated large potential towards the reduction of mineral resource use and CO_2 emissions.

RECYCLING AGENTS

https://doi.org/10.1016/j.jclepro.2023.136994

In these intervening years, some specific advances have been made to propose novel methods for understanding the chemical nature of RAs, how RAP interacts with the virgin binder and RA, and how acceptable performance of recycled asphalt binder blends and mixtures can be achieved through dosage selection methods.

SMART SEGMENTATION

https://doi.org/10.1016/j.jcomc.2021.100137

A new segmentation approach was developed and applied to a reference blade model. The recovered construction elements were found to comply to geometric construction standards and to outperform conventional construction materials on specific flexural stiffness and flexural strength.

BLADES 2 BUILD

www.blades2build.com

The aim of BLADES2BUILD is to improve and support circularity options of end-of-life wind blades by exploring three different circular stages; Direct re-use of the EOL wind blades, Re-purpose of individual materials constituents of the blades, and recycling the blade in cement/clinker co-processing as an alternative fuel.

REFRESH

www.refresh-project.eu/

REFRESH (Smart dismantling, sorting and REcycling of glass Fibre REinforced composite from wind power Sector through Holistic approach) *is a European project to develop and demonstrate a novel circular, smart system enabling improved recycling of glass fibre reinforced composites derived from wind turbine dismantling or reblading.*

ACCIONA

www.experience.acciona.com/

Messengers of the wind: The pioneering shoes with recycled turbine blade soles. *ACCIONA Energía and the fashion brand El Ganso have collaborated on an unprecedented global project: creating sneakers with soles crafted from recycled wind blades.*

INDUSTRY ALLIANCES

Composites World Article

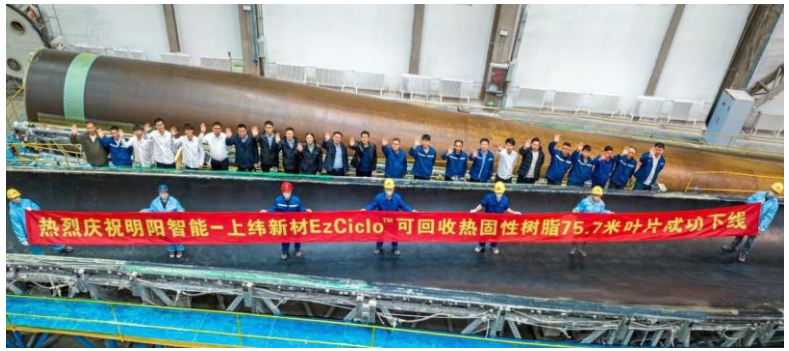
Six partners will deliver a composites circularity model from recycled waste to final boat production as a jumping off point for industries beyond marine.

The Beneteau Group, Veolia, Arkema, Owens Corning, Composite Recycling and Chomarat.

RECYCLABLE WIND BLADES

Siemens Gamesa pioneers wind circularity: launch of world's first recyclable wind turbine blade for commercial use offshore … The chemical structure of this new resin type makes it possible to efficiently separate the resin from the other components at end of the blade's working life. This mild process protects the properties of the materials in the blade, in contrast to other existing ways of recycling conventional wind turbine blades. The materials can then be reused in new applications after separation.

Swancor applies its EzCiclo recyclable thermosetting resin technology to a large-scale Mingyang Smart Energy blade. The blade features a composite of recyclable epoxy pultruded plate and recyclable sandwich core material, utilizing Swancor's EzCiclo recyclable thermosetting resin infusion molding technology. The blade has become an important step in the application of EzCiclo recyclable thermosetting resin to large wind power blades.



USEFUL RESOURCES

- Swancor applies its EzCiclo recyclable thermosetting resin technology to a large-scale Mingyang Smart Energy blade
- Siemens Gamesa pioneers wind circularity: launch of world's first recyclable wind turbine blade for commercial use offshore
- Chemical & Engineering News - Wind turbine blade recycling picks up speed

ZEBRA PROJECT

> *The ZEBRA project is a unique partnership led by the French Institute for Technological Research, IRT Jules Verne. Joining forces are industry leaders Arkema (resin supplier), Owens Corning (glass fiber supplier), LM Wind Power (blade manufacturer), SUEZ (dismantling and waste processing), CANOE R&D center (recycling technology), and ENGIE (life cycle analysis).*

USEFUL RESOURCES

- Arkema - **ZEBRA Project Demonstrates Closed-Loop System**
- LM Wind Power - **Designing Blades Without Waste**
- JEC - **ZEBRA Project - Design for Recycling and Performance with Optimized Materials and Manufacturing Processes**

Arkema developed and validated the generation of recycled Elium® monomer through thermolysis, and, together with its subsidiary Bostik, an innovative adhesive for the blade assembly that is recycled together with Elium® paving the way for industrial-scale implementation.

Owens Corning successfully recovered glass fiber at pilot scale, enabling its reintroduction into the production process for their Sustaina® product line.

LM Wind Power manufactured two wind turbine blades with Arkema's Elium® resin and Owens Corning's Ultrablade® fabrics; one blade including a large structural element made with recycled Elium® resin.

SUEZ provided cutting and grinding expertise for processing the blades.

CANOE R&D Center optimized recycling for production and carbon blade waste, additionally developing methods for repurposing waste streams through mechanical recycling.

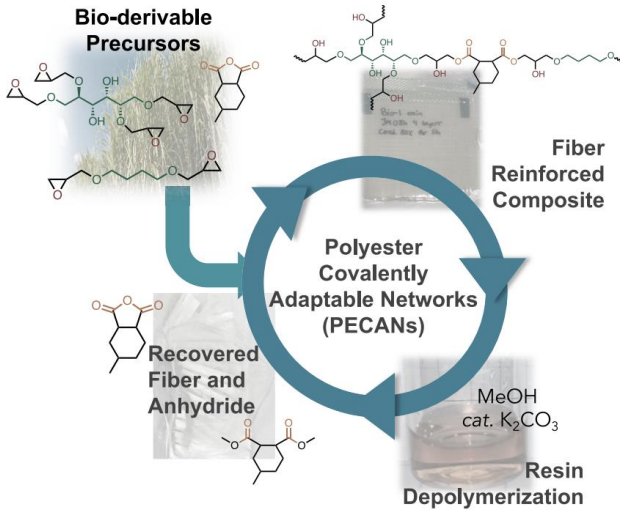
ENGIE conducted a comprehensive life cycle analysis demonstrating the environmental benefits of closed-loop ZEBRA blades and validated their economic viability.

The ZEBRA Project showcased the world's largest glass thermoplastic blade built at 62,2m - Feb 2022

NREL'S PECAN

National Renewable Energy Laboratory

To enable the circularity of FRPs, we formulated a bio-derivable polyester covalently adaptable network (PECAN), sometimes referred to as a polyester vitrimer, to manufacture FRPs at >1 kg scale, which is accomplished as the resin is infusible (175–425 cP at 25°C viscosity), can be cured at 80°C within 5 h and is depolymerizable via methanolysis yielding high-quality fibers and recoverable hardener.



Using current manufacturing process methods and the NREL-developed biomass-derivable resin — which has been nicknamed "PolyEster Covalently Adaptable Network" or PECAN — researchers built a 9-meter prototype blade to demonstrate the resin's manufacturability … PECAN is said to mark a leap forward because of the ability to recycle the blades using mild chemical processes, which enables blade components to be recaptured and reused again and again.

USEFUL RESOURCES

- Composites World - **NREL develops biomass-derived resin PECAN for wind blades**
- Synthesis, characterization, and recycling of bio-derivable polyester covalently adaptable networks for industrial composite applications
- Composites World - **NREL, Arkema research recyclable, thermoplastic composite wind turbine blades**

NREL's PECAN Resin is not only recyclable but also made of bio content.

DECOMBLADES PROJECT

Decomblades

> *In 2023, DecomBlades proved the concept of recovering glass fibres through pyrolysis from old wind turbine blades and remelting it into new fibres is an environmentally viable and scalable solution. The proved pyrolysis-remelting-value-chain can help solve the wind industry's recycling challenge, as it unlocks true circularity for wind turbine blades and can off-take the quantity of blades for the years to come.*

A major leap to address these challenges has taken place. For the first time, recycled glass fibers from old wind turbine blade are being used to produce new glass fibres for wind turbine blades, resulting in the manufacturing of a 115-meter-long blades for Greater Changhua 2b + 4 in Taiwan. This large-scale demonstration enables a fully circular use of glass fibres from and for wind turbines and shows the potential of such recycling route.

USEFUL RESOURCES

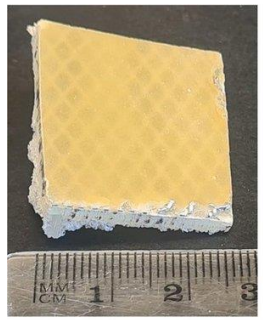
- DTU LinkedIn – **Sustainability starts at the drawing board**
- Makeen Energy LinkedIn – **Recycling is good - but circularity is better**
- Makeen Energy - **Circularity for wind turbine blades**
- Composites World - **DecomBlades project lays groundwork for wind recycling commercialization efforts**

The Decomblades Project was also responsible for developing the Wind Blade Passports with three major wind turbine manufacturers contributing to this sustainability effort, as previously mentioned.

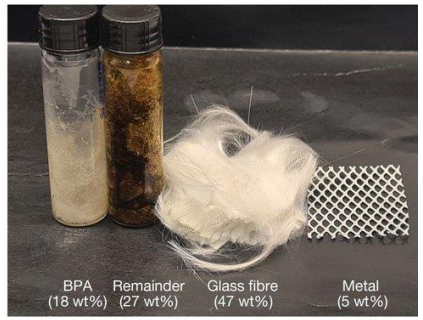
CETEC PROJECT

The CETEC Project

CETEC Partners: developed a technology that enables full recycling of the composite material in wind turbine blades. Through the CETEC (Circular Economy for Thermosets Epoxy Composites) project, a two-part solution has been found to separate the composite materials into fibreglass and epoxy, after which the epoxy is chemically broken down into basic components of the same quality as virgin materials. These can then be reused in new epoxy-based composites.

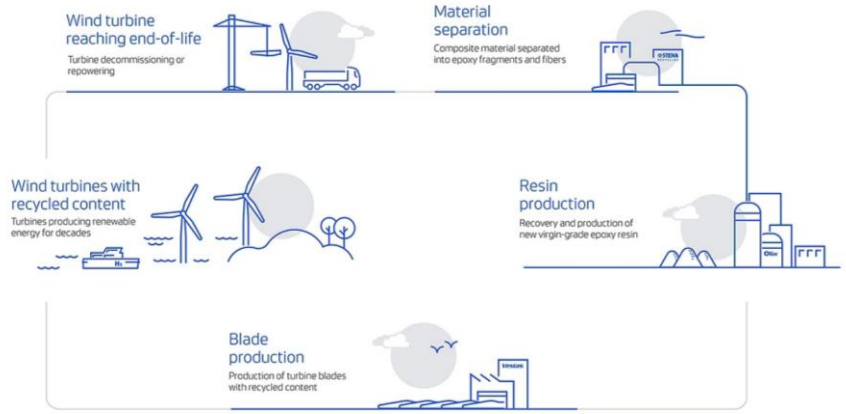

Wind turbine blade (5.13 g)


After catalysis (6 d)



Recovered materials

Within 24 hours a 0.5x0.5m fraction of a standard Vestas blade is dissolved enough to easily separate materials.



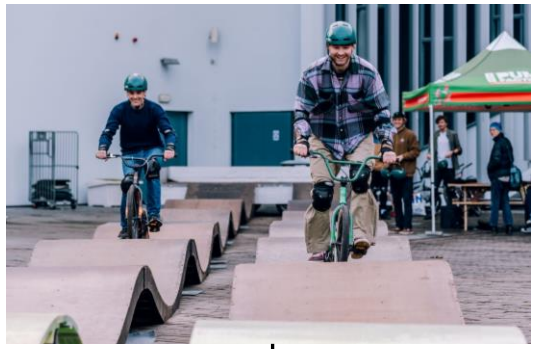
"Chemcycling of epoxy-based materials would allow deconstructing these highly stable polymer chains into molecular building blocks. These building blocks are easily processable and can be utilised to produce new epoxy, which will have the same quality as the original material. Avoiding the loss of valuable molecular complexity in such a way is a highly desirable concept and an important step to sustainable materials," *- Prof. Dr. Troels Skrydstrup*

USEFUL RESOURCES

- **Vestas unveils circularity solution to end landfill of turbine blades**
- Danish Technological Institute - **Composites - Recycling and Circularity**
- Composites World - **CETEC initiative established to commercialize technology for full composite wind turbine blade recyclability**

REPURPOSING – NEW ARCHITECTURE WITH OLD BLADES

Wind turbine turned into compact living by Vattenfall



Pumptrack by TU Delft's Faculty of Industrial Design Engineering

Discarded Wind Turbine Blades Are Upcycled into Sleek Bike Shelters by Siemens Gamesa

Wikado playground by BladeMade in The Netherlands

BladeBridge repurposes decommissioned wind turbine blades into sustainable infrastructure.

TRÆ – an example of End-Of-Life wind turbine blades incorporated into architectural design of a building.