University of Exeter

Dr. Stuart Walker

Glass or grass?

Combining material data and life cycle assessment to compare conventional and biologically-based tidal stream turbine blades

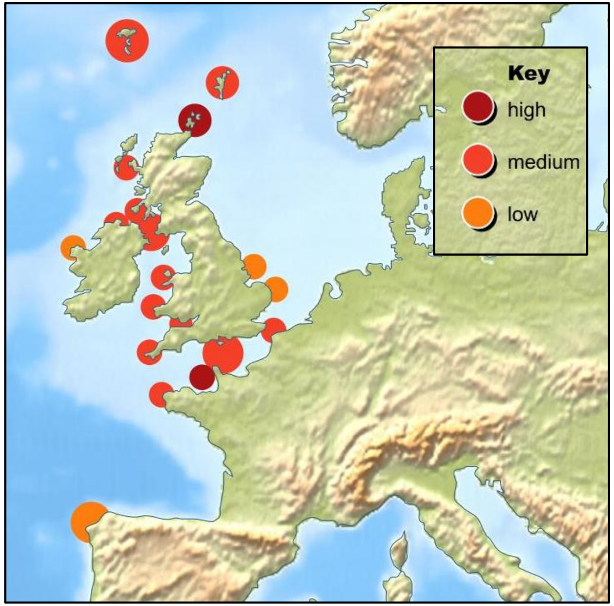
Tidal stream energy & TIGER

Tidal stream energy is a renewable technology. It is:

- Environmentally friendly (low CO_2 emissions)
- Network friendly (predictable, no intermittency)
- NIMBY friendly (low visual impact)

However it is also:

- Currently expensive
- Not yet deployed at significant scale
- Developing slowly



Aqua-RET project estimated tidal stream resource (aquaret.com)

University of Exeter

TIGER TIDAL STREAM INDUSTRY ENERGISER

Interreg France (Channel Manche) England

EUROPEAN UNION

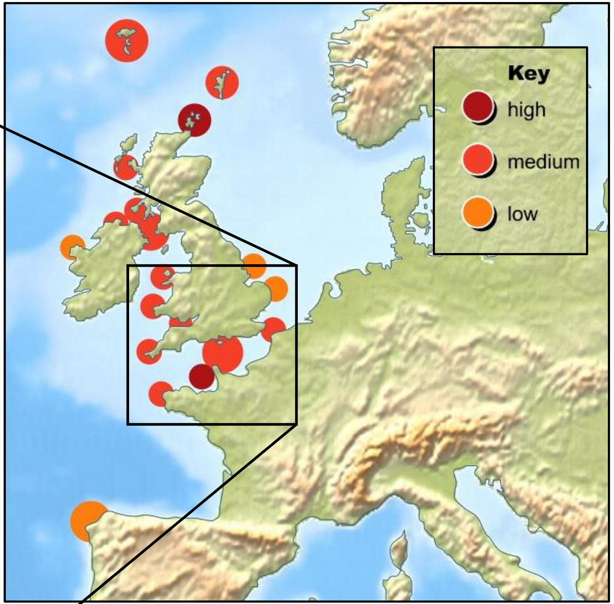
Tidal stream energy & TIGER

Tidal stream energy is a renewable technology. It is:

- Environmentally fr
- Network friendly (p
- NIMBY friendly (lov

However it is also:

- Currently expensiv
- Not yet deployed o
- Developing slowly



Aqua-RET project estimated tidal stream resource (aquaret.com)

University of Exeter

TIGER TIDAL STREAM INDUSTRY ENERGISER

Interreg France (Channel Manche) England

EUROPEAN UNION

Tidal stream energy & TIGER

Tidal stream energy is a renewable technology. It is:

- Environmentally fr
- Network friendly (p
- NIMBY friendly (lo

However it is also:

- Currently expensiv
- Not yet deployed o
- Developing slowly

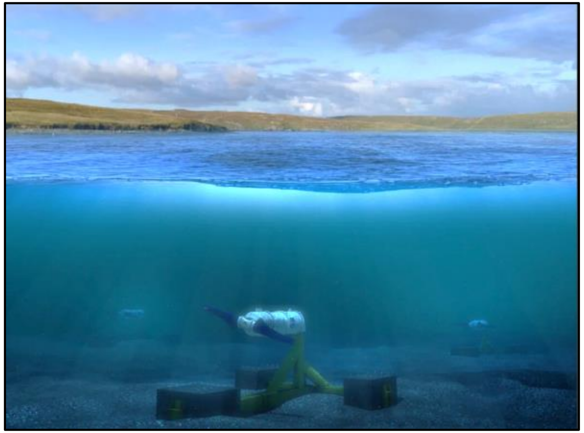
Aqua-RET project estimated tidal stream resource (aquaret.com)

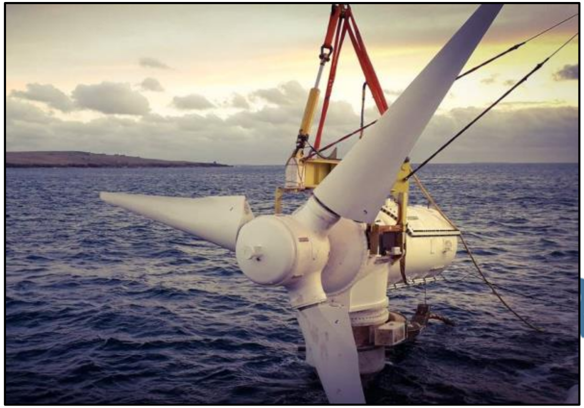
University of Exeter

TIGER TIDAL STREAM INDUSTRY ENERGISER

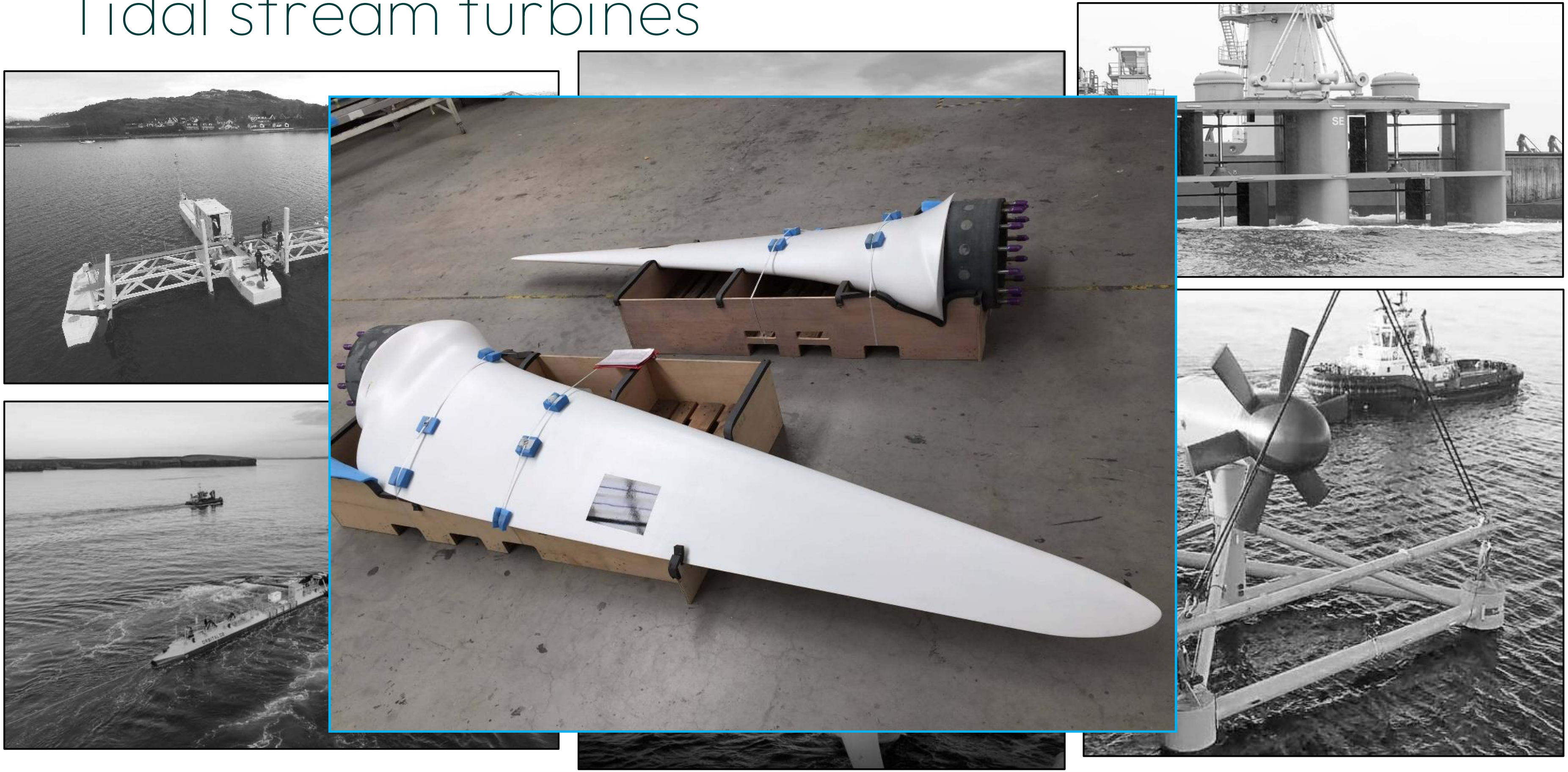
Interreg France (Channel Manche) England
EUROPEAN UNION

Tidal stream turbines



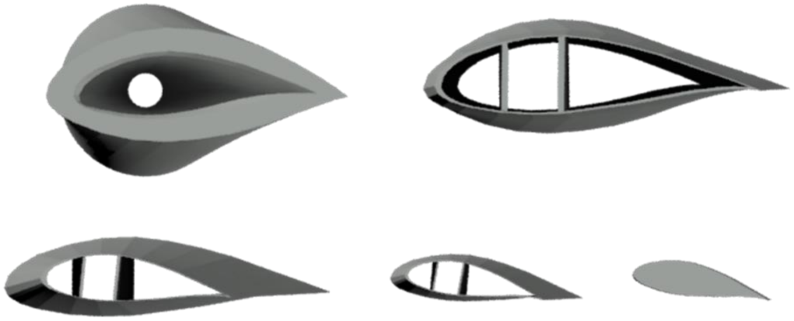


Tidal stream turbines



Turbine blade environment

- Seawater is much denser than air
- The marine environment is notoriously harsh
- Turbines are designed for 20-25 years of life with maintenance perhaps every5 years
- Storm conditions and impacts are harder to avoid
- Though some challenges are similar, tidal and wind blades are different



University of Exeter

TIGER TIDAL STREAM INDUSTRY ENERGISER

Interreg France (Channel Manche) England

EUROPEAN UNION

Overview

Conventional composites perform very well but have some negative environmental impacts

⇩

Bio-based composites may avoid environmental impacts, but their performance is not as good

⇩

This work aims to combine environmental and performance models to compare the full life cycle impact of a component

University of Exeter

TIGER TIDAL STREAM INDUSTRY ENERGISER

Interreg France (Channel Manche) England EUROPEAN UNION

Conventional composite materials

- Glass fibre and carbon fibre turbine blades perform well but are difficult to dispose of.
- As more tidal and wind turbines reach the end of life, this need for disposal represents a challenge and a public perception risk.
    - Each 50 m wind turbine blade ≈ 13,000 kg
    - Each 107 m blades GE Halide-X ≈ 55,000 kg

- Total in-service mass by 2050:
- ≈ 20 Mt wind + 60,000 t tidal

University of Exeter

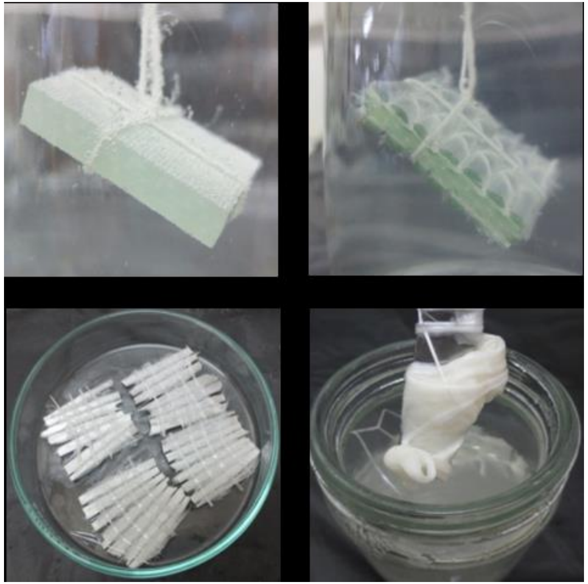
Biologically-based composite materials

- Composite materials can be made using a range of natural fibres: Flax, jute, hemp, kenaf, sisal, coir
- Fibres can be specifically farmed or waste products from other processes
- Epoxy or polyester resins can be used
- In this work we focussed on flax

University of Exeter

Biologically-based composite materials

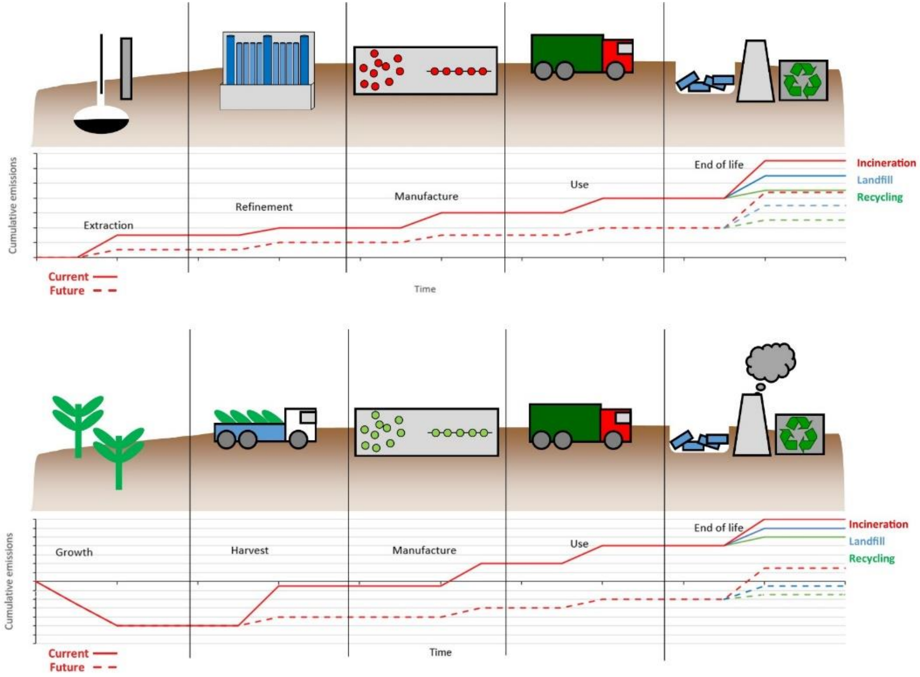
- Our flax composite example material is based on a flax-polyester resin composite.
- A recovery solution is required to separate the composite and the resin at the end of life, meaning that the fibres can be biodegraded and the polyester can be downcycled.
- 25% acetic acid solution: 12 hours at 80°C, then neutralised with a 5% sodium hydroxide solution.



University of Exeter

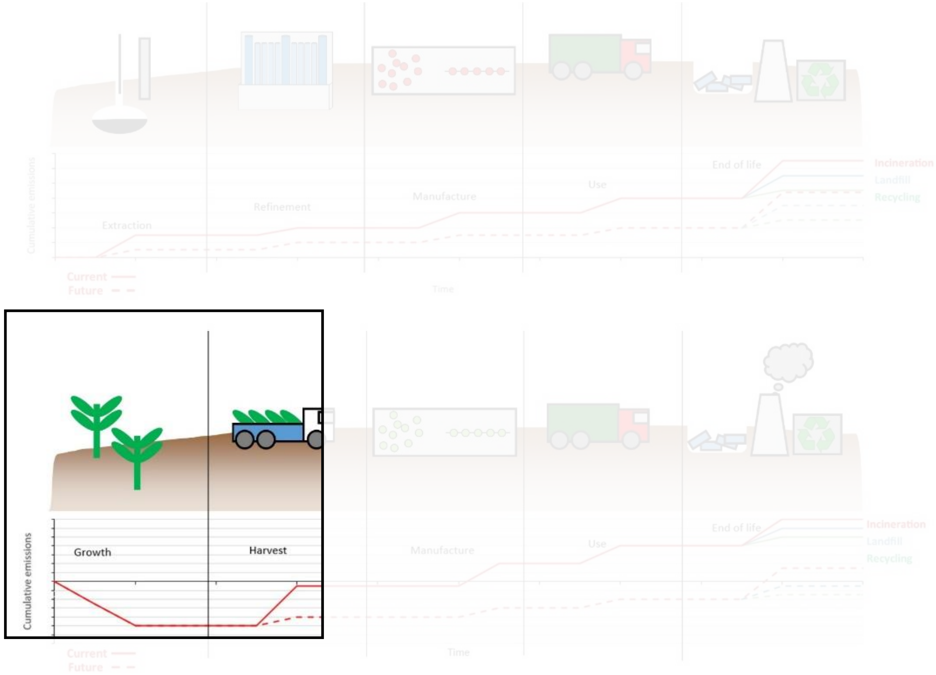
ADITYA BIRLA CHEMICALS

Impact



- The potential of a bio-based material is derived from its absorption of atmospheric CO_2 during growth
- This gives these materials a "head start" over fossil-based materials
- However, if much more material and/or processing is required, bio-based materials may not actually have lower life cycle emissions

Impact



- The potential of a bio-based material is derived from its absorption of atmospheric CO_2 during growth
- This gives these materials a "head start" over fossil-based materials
- However, if much more material and/or processing is required, bio-based materials may not actually have lower life cycle emissions

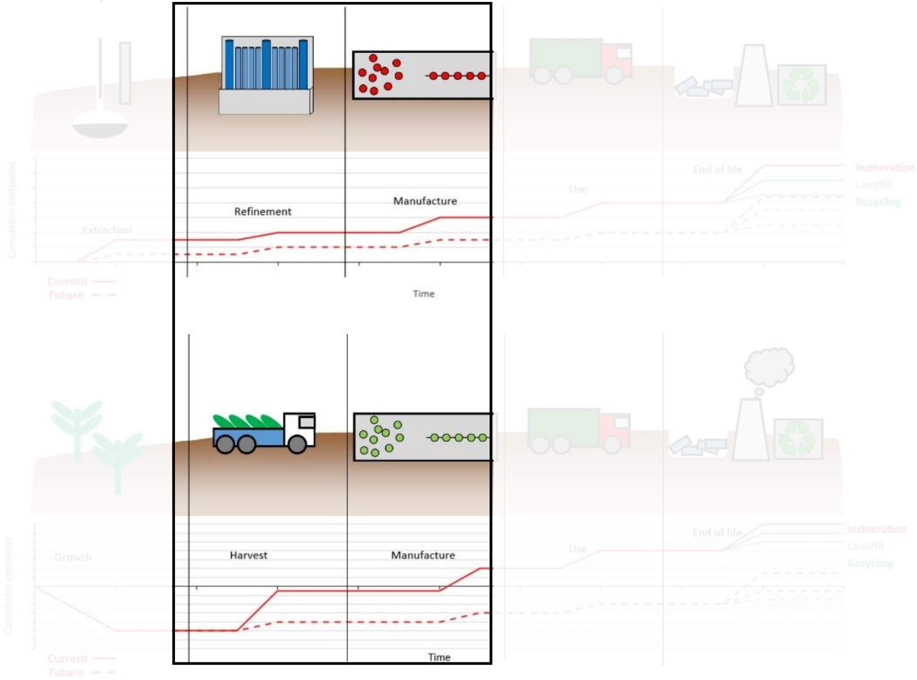
University of Exeter

TIGER TIDAL STREAM INDUSTRY ENERGISER

Interreg France (Channel Manche) England

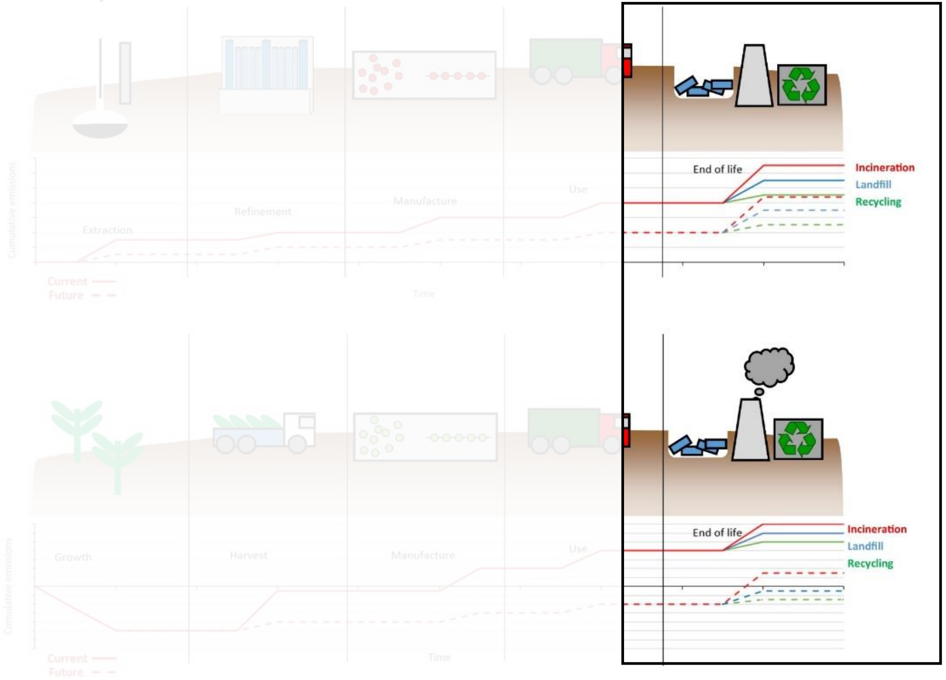
EUROPEAN UNION

Impact



- The potential of a bio-based material is derived from its absorption of atmospheric CO_2 during growth
- This gives these materials a "head start" over fossil-based materials
- However, if much more material and/or processing is required, bio-based materials may not actually have lower life cycle emissions

Impact



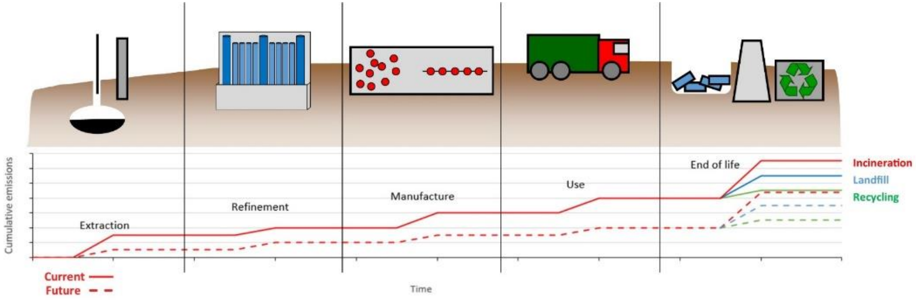
- The potential of a bio-based material is derived from its absorption of atmospheric CO_2 during growth
- This gives these materials a "head start" over fossil-based materials
- However, if much more material and/or processing is required, bio-based materials may not actually have lower life cycle emissions

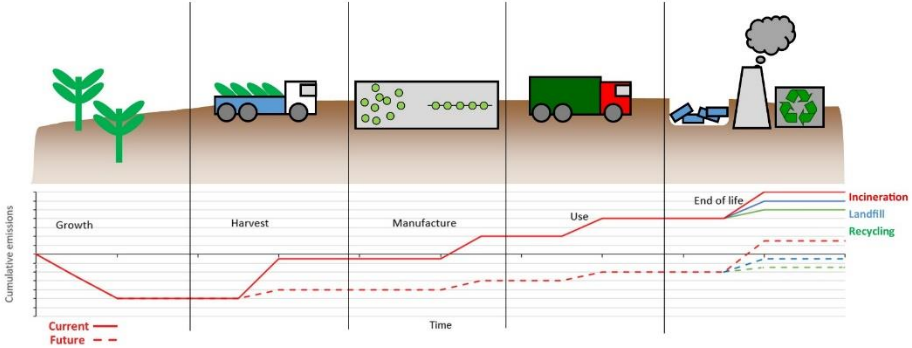
University of Exeter

TIGER TIDAL STREAM INDUSTRY ENERGISER

Interreg EUROPEAN UNION France (Channel Manche) England

Impact



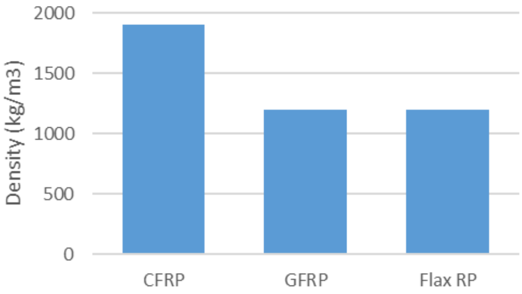


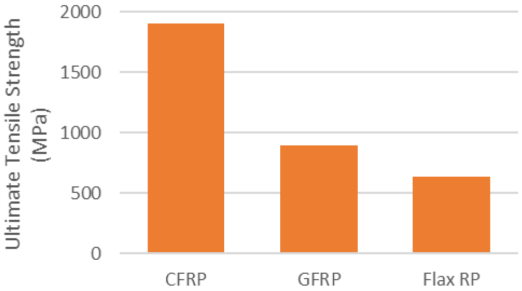
- The potential of a bio-based material is derived from its absorption of atmospheric CO_2 during growth
- This gives these materials a "head start" over fossil-based materials
- However, if much more material and/or processing is required, bio-based materials may not actually have lower life cycle emissions
- This gives two key questions:
  - How much more material and processing is required if a bio-based material is used?
  - Including this, is the impact of bio-based blades greater or less than conventional composites?

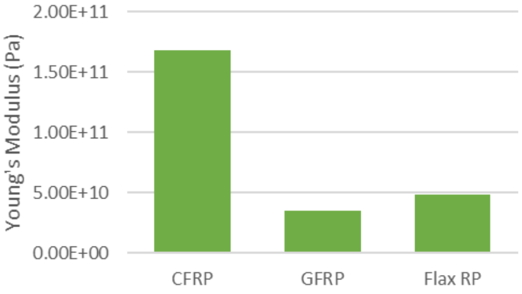
University of Exeter

The performance gap

- Bio-based composites have lower density and lower tensile strength than conventional composites, and lower Young's Modulus than GFRP.
- Based on this data we built a Finite Element model to estimate the mass of material required in each case







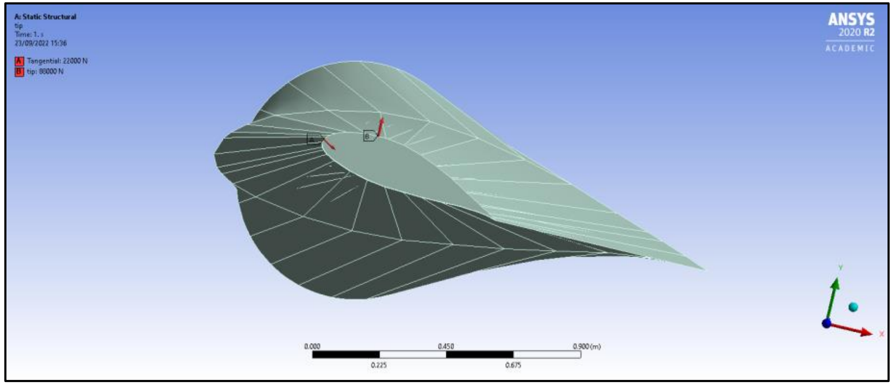
University of Exeter

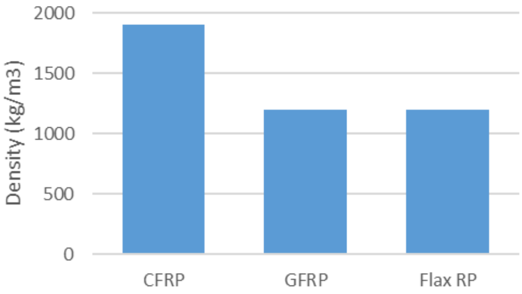
The performance gap

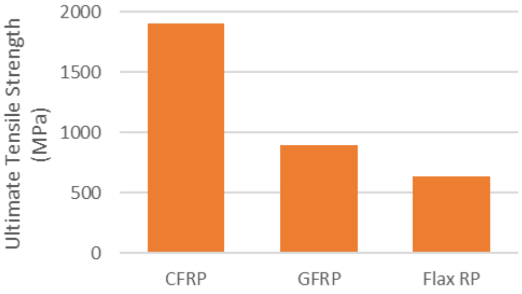
- Bio-based composites have lower density and lower tensile strength than conventional composites, and lower Young's Modulus than GFRP.
- Based on this data we built a Finite Element model to estimate the mass of material required in each case

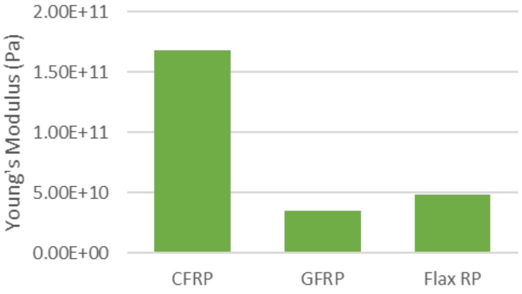
$$F_A = \frac{1}{2} A_A \rho v^2$$

$$F_T = \frac{1}{2} A_T \rho (v\lambda)^2$$



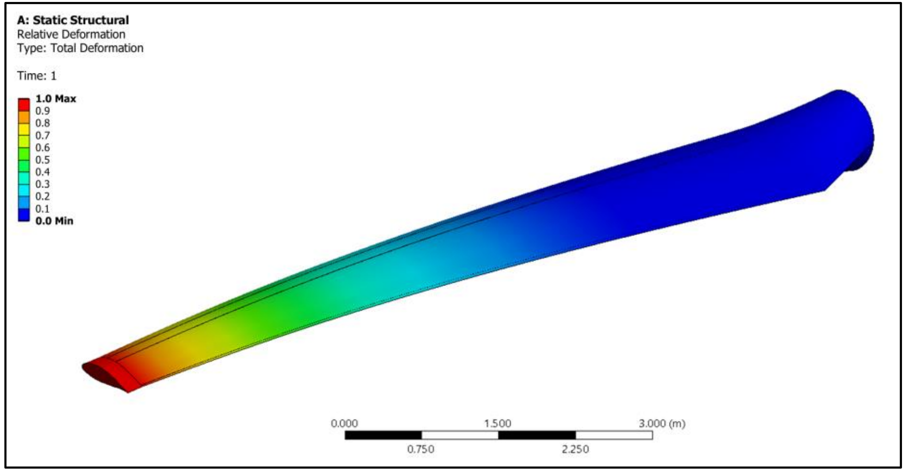






University of Exeter

The performance gap



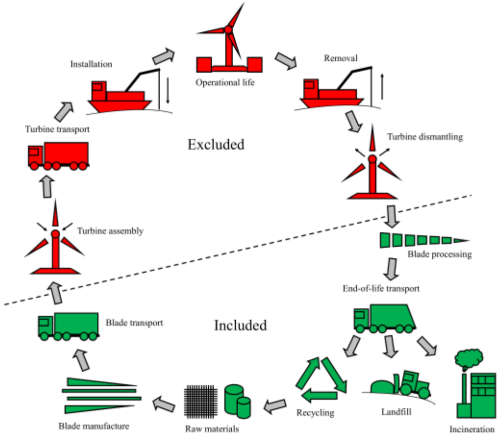
Results indicated the mass of each material required to produce a blade with comparable deflection to a GFRP baseline:

- GFRP: 2530 kg
- CFRP: 1024 kg
- Flax: 1489 kg

This is an area of the work which could be developed. It would be beneficial to expand beyond UTS and Young's Modulus, and to produce more specific FE models including material specific designs.

Environmental impact

- We then generated life cycle assessment (LCA) models for the same blade and material cases.
- Models include materials, manufacturing, transport, and various end-of-life treatments.



P Inputs/Outputs: Flax Turbine blade (EOL and transport)

Inputs

Flow	Category	Amount	Unit	Costs/Reve...	Uncertainty	Avoided wa...	Provider	Data quality...	Description
adhesive, for metal	202:Manufacture of other ...	adhesive_mass	kg		none		market f...		8mat - th...
air compressor, screw-type compr...	281:Manufacture of gener...		Item(s)		none		market f...		
alkyd paint, white, without solven...	202:Manufacture of other ...	paint_mass	kg		none		market f...		1mat
electricity, medium voltage	351:Electric power generat...	vacuum_process	kWh		none		market ...		vacuum ...
epoxy resin, liquid	201:Manufacture of basic ...	epoxy_gelcoat_...	kg		none		market f...		2mat
epoxy resin, liquid	201:Manufacture of basic ...	epoxy_mass	kg		none		market f...		4mat
fibre, flax	131:Spinning, weaving an...	flaxfibre_mass	kg		none		market f...		
heat, district or industrial, natural ...	351:Electric power generat...	heathold_proce...	kWh		none		market ...		curing - ...
heat, district or industrial, natural ...	351:Electric power generat...	heatup_process	MJ		none		market ...		curing - h...
injection moulding	222:Manufacture of plasti...	injection_proce...	kg		none		injectio...		
Paint spraying process		gelcoating_pro...	m2		none		Paint sp...		paint spra...
Paint spraying process		painting_process	m2		none		Paint sp...		gelcoat s...
polyurethane, rigid foam	201:Manufacture of basic ...	foam_mass	kg		none		market f...		6mat
power sawing, with catalytic conv...	161:Sawmilling and planin...	powersaw_proc...	h		none		power s...		perimeter...
steel removed by milling, large pa...	259:Manufacture of other ...	steelremoved_p...	kg		none		market f...		root face ...
steel, low-alloyed, hot rolled	241:Manufacture of basic ...	steel_mass	kg		none		market f...		7mat
styrene	201:Manufacture of basic ...	styrene_gelcoat...	kg		none		styrene ...		3mat - ha...
transport, freight, lorry 16-32 metr...	492:Other land transport/...	road_transport	t*km		none		market f...		
transport, freight, sea, container s...	501:Sea and coastal water ...	0.00000	t*km		none		market f...		zero as in ...

Outputs

Flow	Category	Amount	Unit	Costs/Reve...	Uncertainty	Avoided pro...	Provider	Data quality...	Description
1 GB Flax RP turbine blade		**1.00000**	**Item(s)**		**none**				
Blade disposal incineration		sum_mass	kg		none		Blade di...		
municipal solid waste	382:Waste treatment and ...	0.00000	kg		none		treatme...		

University of Exeter

Manufacturing processes

- We assumed resin transfer moulding (VARTM) was used in all composite blade manufacturing cases in this study.
- A relevant proportion of all manufacturing plant is allocated to each blade.
- The same principal applies to all major equipment, facilities, ships/trucks etc.

NB: Previous work has suggested that powder epoxy has greater environmental impact than VARTM, particularly in air quality impacts

University of Exeter

Results

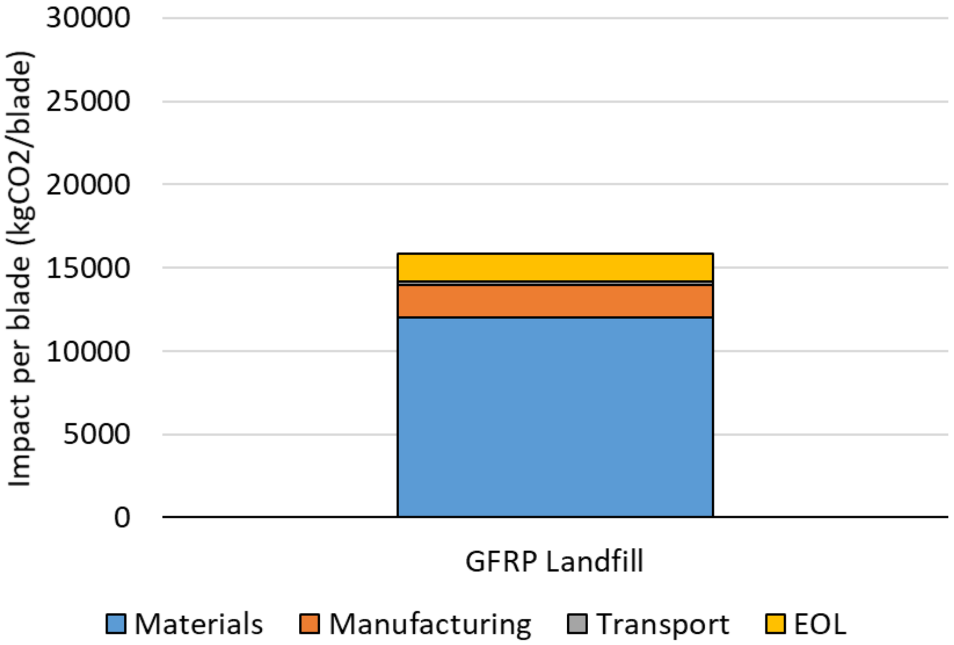
- In each material case:

(Mass of material required X Impact of material per kg) + Impact of non-material processes = **Total impact of blade**

- Additional cases can be developed almost endlessly:
  - Material sources (inc. transport)
  - End-of-life treatments (e.g. biodegradation performance)
  - Differences in maintenance requirements between materials

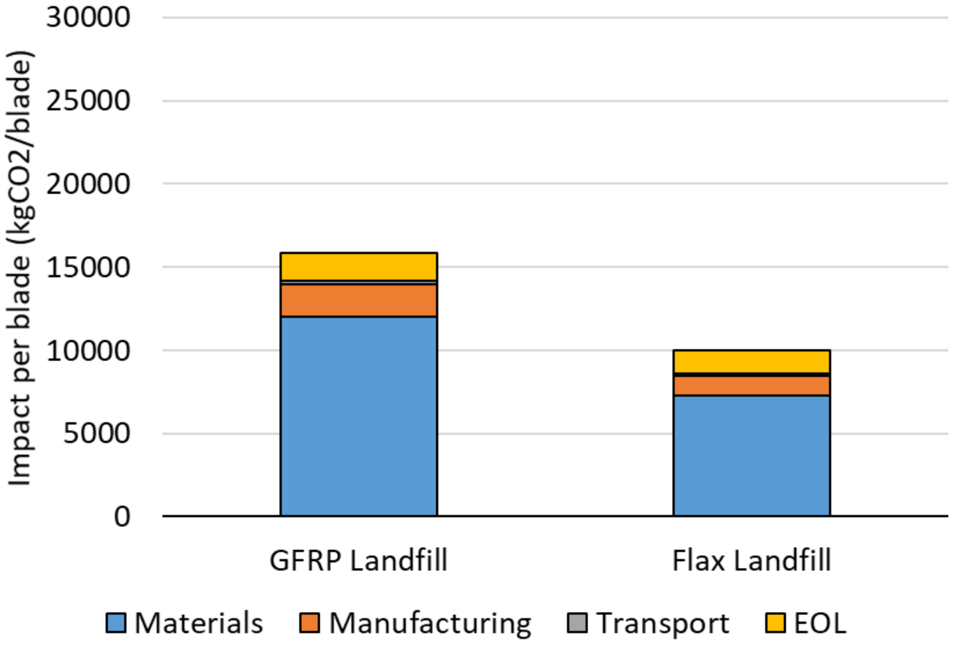
Headline results: Glass or Grass?

- Greenhouse gas impacts: GFRP blade sent to landfill



Headline results: Glass or Grass?

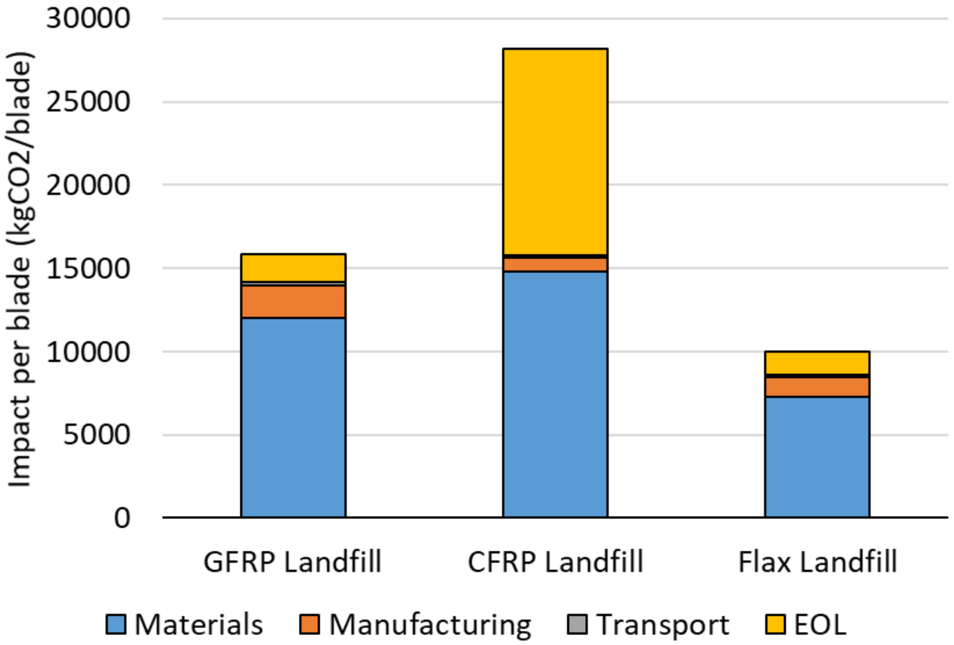
- Greenhouse gas impacts: GFRP blade sent to landfill vs Flax blade sent to landfill



University of Exeter

Headline results: Glass or Grass?

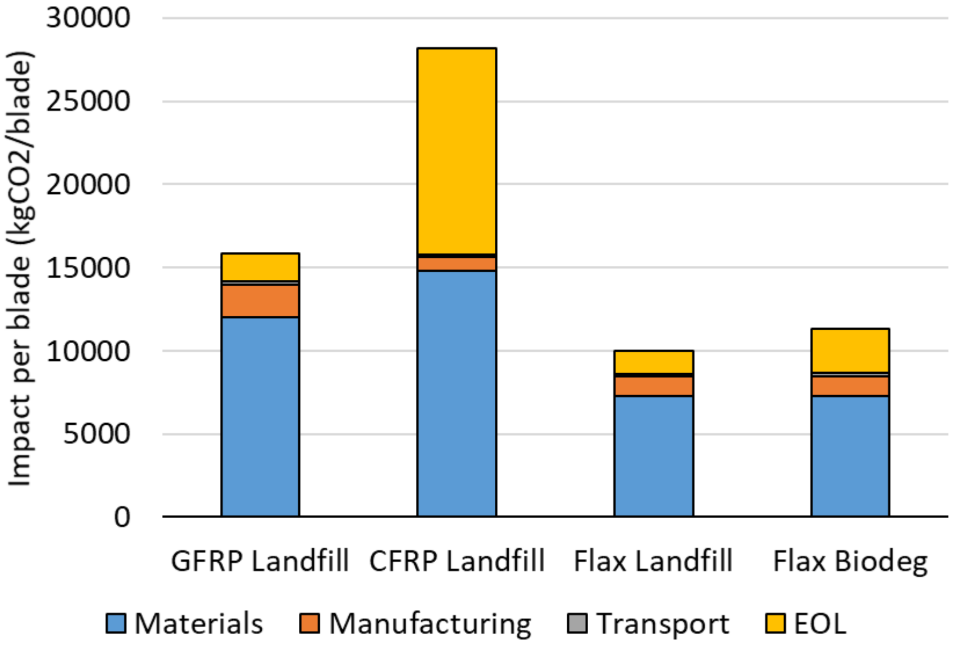
- Greenhouse gas impacts: GFRP blade sent to landfill vs Flax blade sent to landfill vs CFRP blade send to landfill



University of Exeter

Headline results: Glass or Grass?

- Greenhouse gas impacts: GFRP blade sent to landfill vs Flax blade sent to landfill vs CFRP blade send to landfill vs Flax blade recovered, recycled and biodegraded



University of Exeter

Headline results: Glass or Grass?

The impact of bio-based materials is significantly impacted by:

- Source of feedstock (Waste? Food crop replacement?)
- Additional manufacturing requirements (Synthesis, polymerisation)
- Additional processing requirements (Recovery solution)

At present, it appears bio-based materials offer a small improvement in the environmental impact for a turbine blade, but further work on long-term and marine performance is required.

In time, with economies of scale and possible disposal regulations, these materials may well offer advantages over conventional composites

Headline results: Glass or Grass?

The impact of bio-based materials is significantly impacted by:

- Source of feedstock (Waste? Food crop replacement?)
- Additional manufacturing requirements (Synthesis, polymerisation)
- Additional processing requirements (Recovery solution)

At present, it appears bio-based materials offer a small improvement in the environmental impact for a turbine blade, but further work on long-term and marine performance is required.

In time, with economies of scale and possible disposal regulations, these materials may well offer advantages over conventional composites

Headline results: Glass or Grass?

The impact of bio-based materials is significantly impacted by:

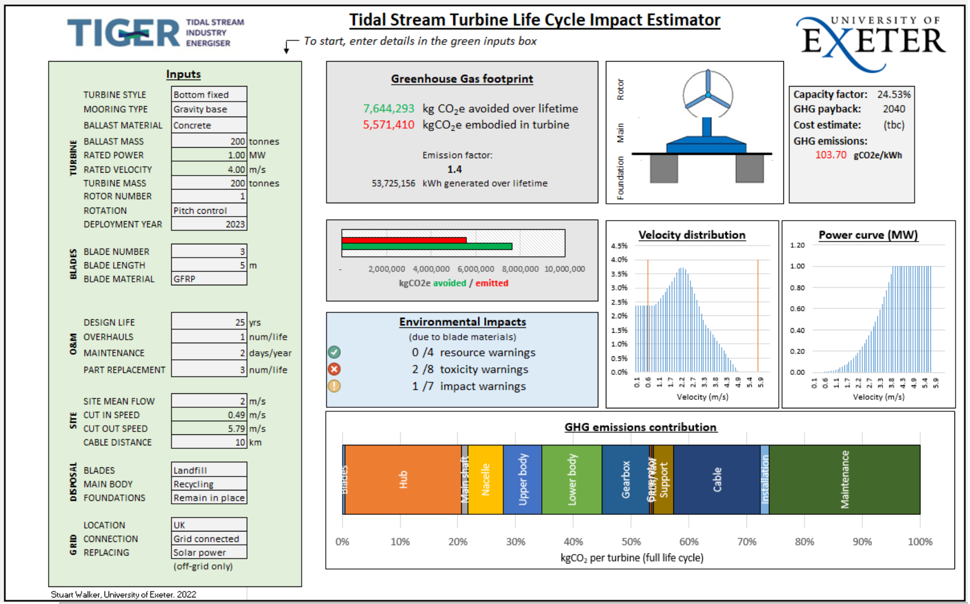
- Source of feedstock (Waste? Food crop replacement?)
- Additional manufacturing requirements (Synthesis, polymerisation)
- Additional processing requirements (Recovery solution)

At present, it appears bio-based materials offer a small improvement in the environmental impact for a turbine blade, but further work on long-term and marine performance is required.

In time, with economies of scale and possible disposal regulations, these materials may well offer advantages over conventional composites

Next steps

- We have extended the LCA work into a full turbine model, with 1000s of material and design variations
- Using this tool we can estimate the impact of any turbine design in minutes (vs weeks) and can hold some features whilst optimising others for lowest impact
- Bio-based material impact depends heavily on the plant material. We are working on developing materials from food crop waste



University of Exeter

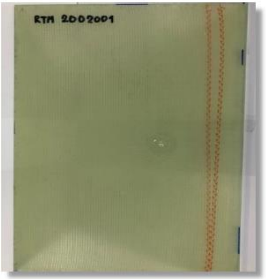
Thank you

Questions?

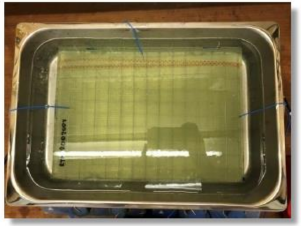
s.walker7@exeter.ac.uk

Thanks to TIGER, the Exeter TIGER team (Lars Johanning, Philipp Thies, Ian Ashton, Helen Smith, Ed Mackay and Jon Hardwick), and Peter for the invitation.

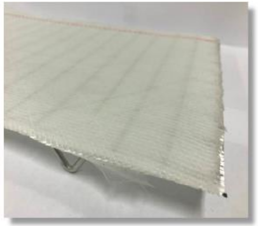
Recovery process



GRE Laminate
(from 3Ax 1200 gsm)

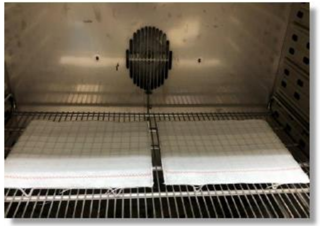


GRE Laminate immersed in recovery solution
& Conditioned @ 80-90°C for 6 hrs.



Recovered glass fabric
after recycling process

Rinsing with potable water



Drying at 120°C/ 2 hrs.

Dried - Recovered glass fabric

University of Exeter