ELG Carbon Fibre Ltd.
RECYCLED CARBON FIBRE

Recycled Carbon Fibre as an Enabler for Cost Effective Lightweight Structures

Global Automotive Lightweight Materials
Detroit, 2016

Overview of ELG Carbon Fibre

- Established in 2011 when ELG Haniel acquired the operations of Recycled Carbon Fibre Ltd.
- Patented process for recovery of carbon fibre from manufacturing waste and end-of-life products, using a modified pyrolysis process. Recovered and converted more than 1000 tonnes of carbon fibre in 2015.
- R&D programmes have led to the development of recycled carbon fibre products for the compounding and composites industries.
- **Goal: to provide affordable, high performance materials to enable weight reduction in the transportation market.**

What We Do

Carbon Fibre Reclaiming

- Metal removal and cutting of large composite structures to sizes suitable for downstream processing.
- Shredding of laminates and prepreg to enable efficient and consistent processing.
- Fibre recovery via a modified pyrolysis process.

Carbon Fibre Conversion

- Milling.
- Nonwoven mat production.
- Pellet production.

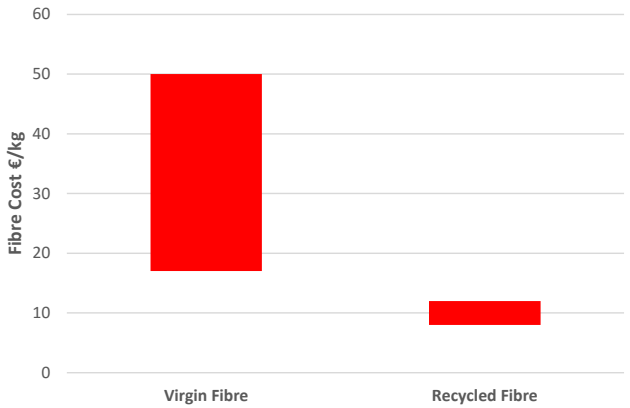
Product Research and Development

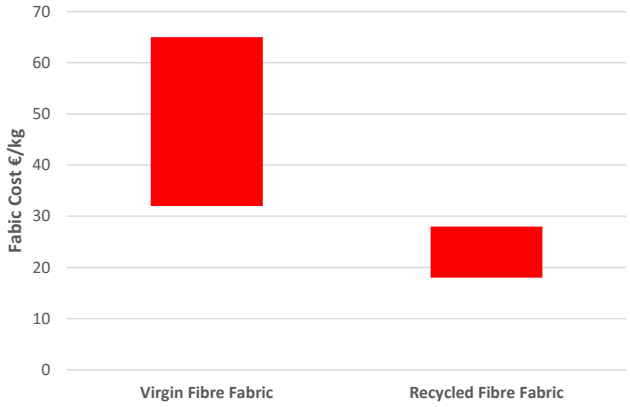
- Aligned fibre materials.
- Intermediate materials (e.g. SMC)

Why Recycled Carbon Fibre?

Affordability

- Demand for carbon fibre was estimated at 79,000 tonnes in 2015 (1).
- Almost 24,000 tonnes of this fibre became waste during conversion and component manufacturing processes.
- Less than 10% of this waste carbon fibre was recycled—most was consigned to landfill.
- Recovering and converting this carbon to products for the compounding and composites industries provides a source of affordable, high performance materials.



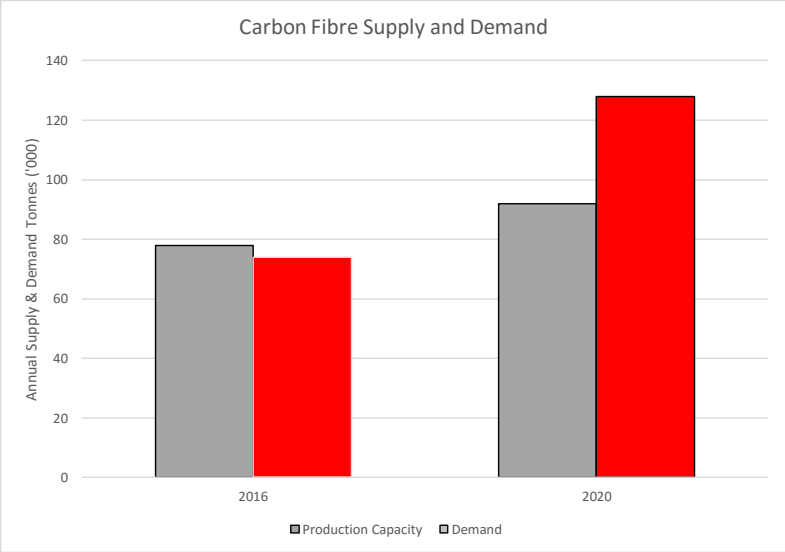


(1) Global Outlook for Carbon Fibre The Past (2010), the Present (2015), and the Future (2020):Chuck Segal, Managing Director, OMNIA LLC and Chris Red, Principal, Composites Forecasts and Consulting, LLC

Why Recycled Carbon Fibre?

Supply Chain Security

- Demand for carbon fibre forecast to grow to 120,000—145,000 tonnes in 2020 (1,2).
- 25,000 tonnes of this growth expected to come from automotive applications.
- Although with new investment, nameplate capacity may match demand, actual capacity is some way below nameplate and there is a supply side capacity risk.
- Use of recycled carbon fibre products mitigates this supply side capacity risk.



Recycling of manufacturing waste can help fill the potential gap between carbon fibre supply and demand

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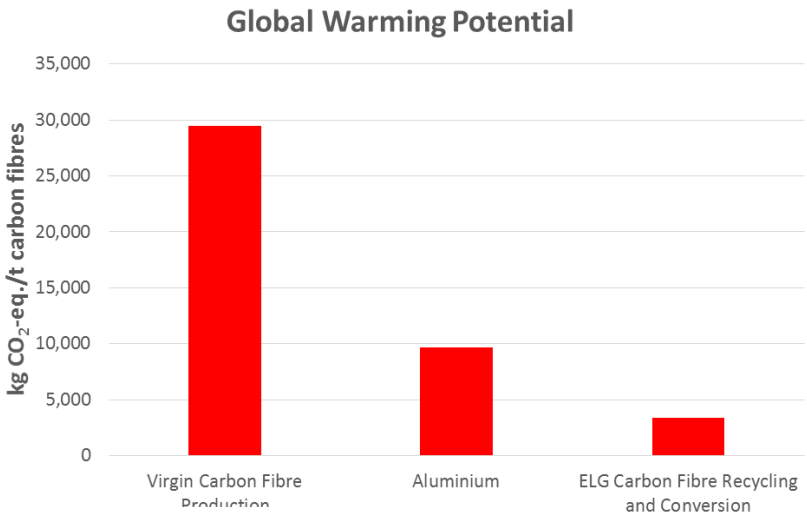
Why Recycled Carbon Fibre?

Environmental Responsibility

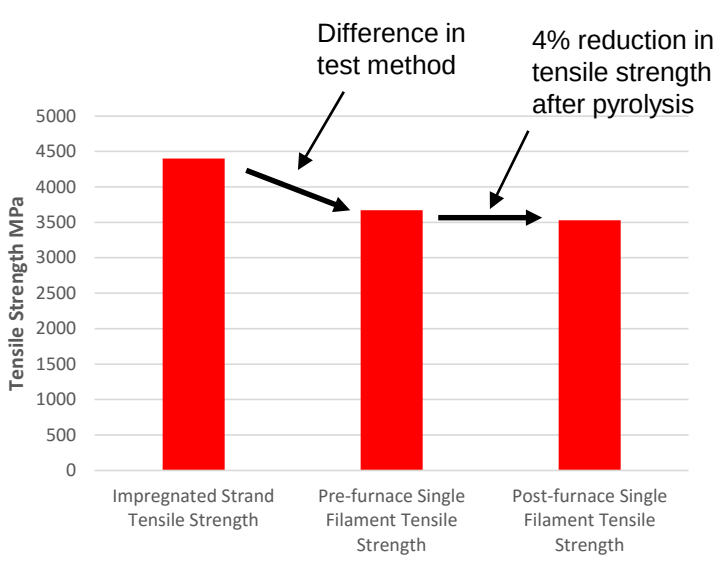
- Carbon fibre production is energy intensive—30 tonnes CO_2eq are produced for every tonne of carbon fibre made.
- Consigning this material to landfill is not an environmentally responsible approach.
- Carbon fibre waste can be recovered and converted to new products using less than 10% opf the energy required to produce the original carbon fibre.

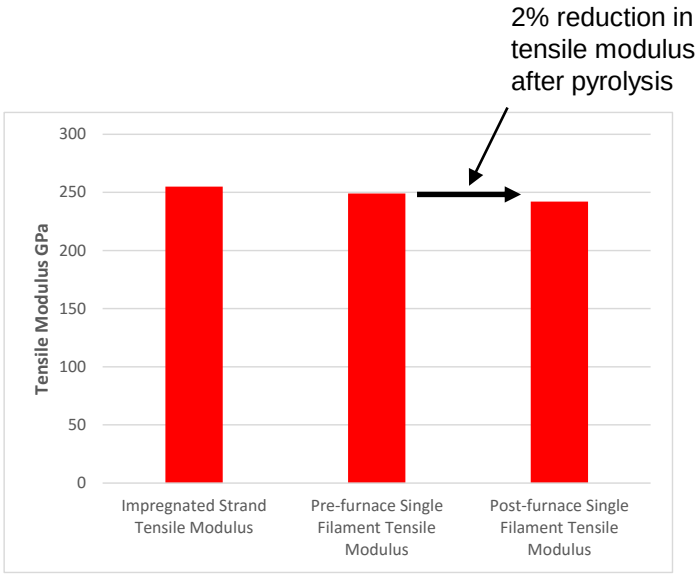


Global warming potential comparison prepared by Fraunhofer UMSICHT based on ELG CF 2014 operational data. Further 36% reduction in energy consumption per kg achieved in 2015.

Fibre Quality

- Fibre mechanical properties measured using single filament testing before and after pyrolysis for classification and quality control purposes.





- Reclaimed carbon fibres have similar mechanical properties to the original fibres provided that the reclaiming process is optimised for the type of feedstock being treated.

Based on single filament testing of 1484 fibre batches before and after fibre recovery by pyrolysis.

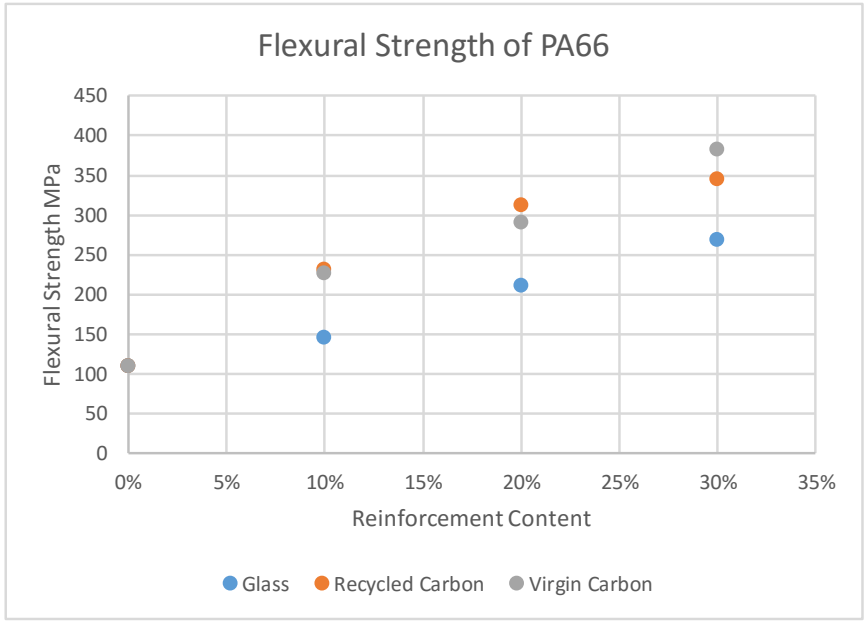
Recycled Carbon Fibre in Compounds

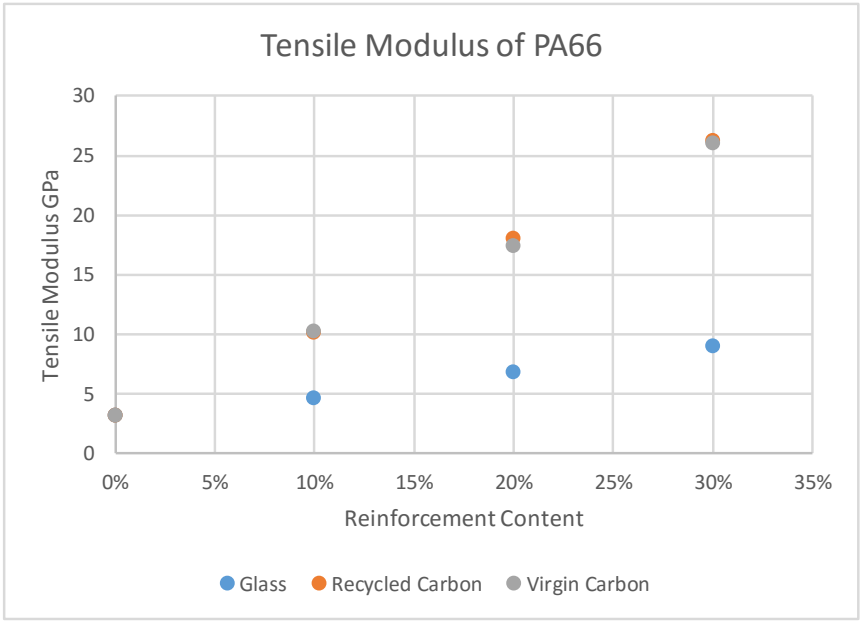
- Milled, chopped and pelletised carbon fibre are ideally used for reinforcing thermoset and thermoplastic compounds.
- Mechanical properties match or exceed those that can be achieved with virgin carbon fibre, but at a lower cost.
- Lower cost carbon reinforced compounds open the possibility to replacing not only magnesium and aluminium, but also glass fibre.

Milled Fibre

Pellets

Mechanical Properties of rCF Compounds





- Recycled carbon fibres give the same mechanical property enhancement as virgin carbon fibres.
- 10% loading of recycled carbon fibre provides the same mechanical properties as 30% loading of glass fibres.
  - 23% density reduction.
  - 4% material cost increase.
- 30% to 45% loadings of recycled carbon fibre provide mechanical properties comparable to magnesium castings and aluminium castings.

Performance comparison

15% weight reduction

30% glass fibre reinforced PA66
56.9g

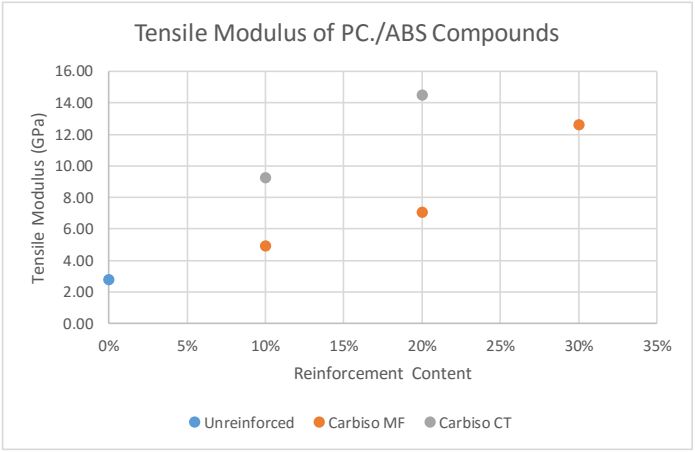
10% rCF reinforced PA66
48.7g

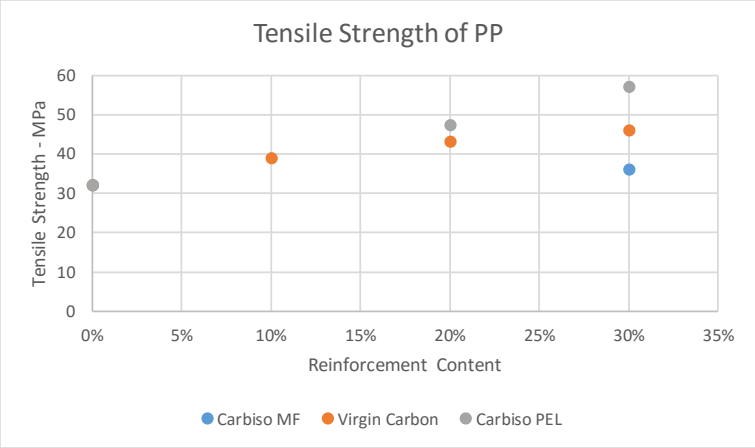
Higher mechanical properties

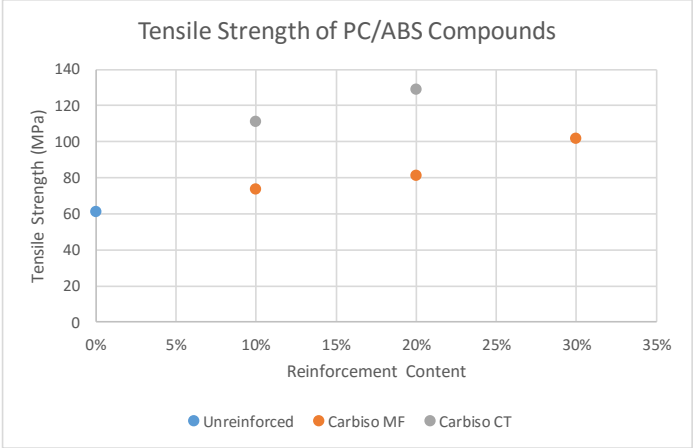
- With product optimization, 21% weight reduction can be achieved whilst providing the same mechanical performance without redesigning the parts.
- Part cost increase to achieve this weight saving ~2%.
- Over 750,000 tonnes of 30% glass reinforced PA66 compounds used for air inlet manifolds and cam covers each year by the automotive industry—potential for over 150,000 tonnes of weight saving!

Other Polymers

- PC/ABS—significant enhancements in strength and stiffness can be achieved.
- PP—recycled carbon fibres show improved properties compared to virgin carbon fibres—attributed to better fibre/resin compatibility.





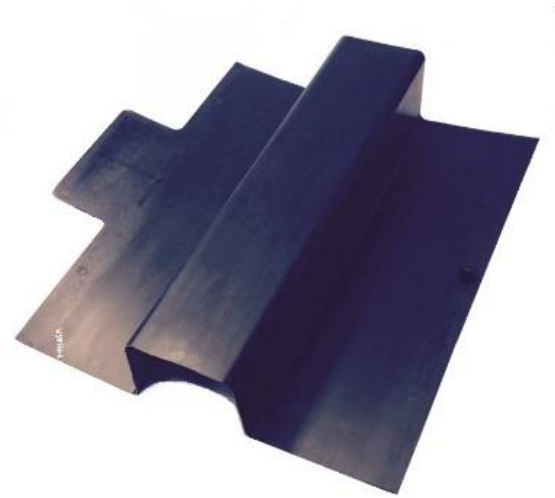


Recycled Carbon Fibre in Composites

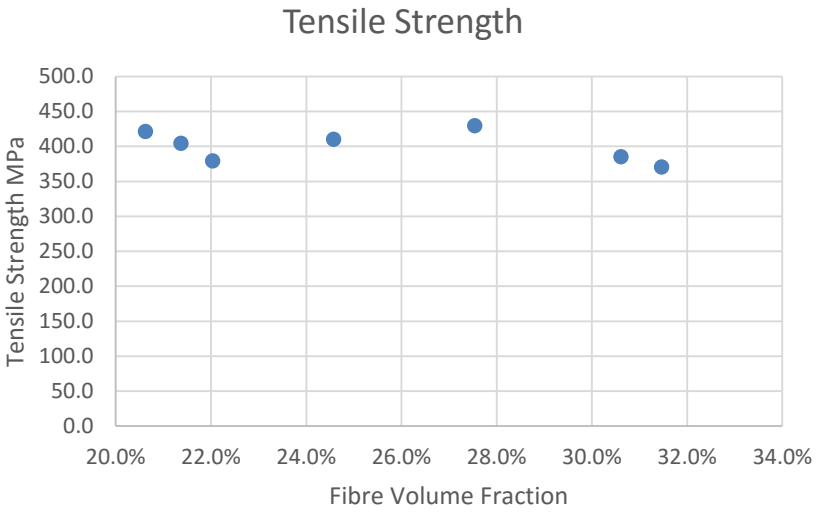
- Nonwoven mats are the basis of the products for composites manufacturing.
- These can be either 100% carbon fibre or blends of carbon fibre with thermoplastic fibres.
- Carbon fibre products can be used in liquid, prepreg and SMC applications.
- Hybrid products can be used in compression moulding applications.

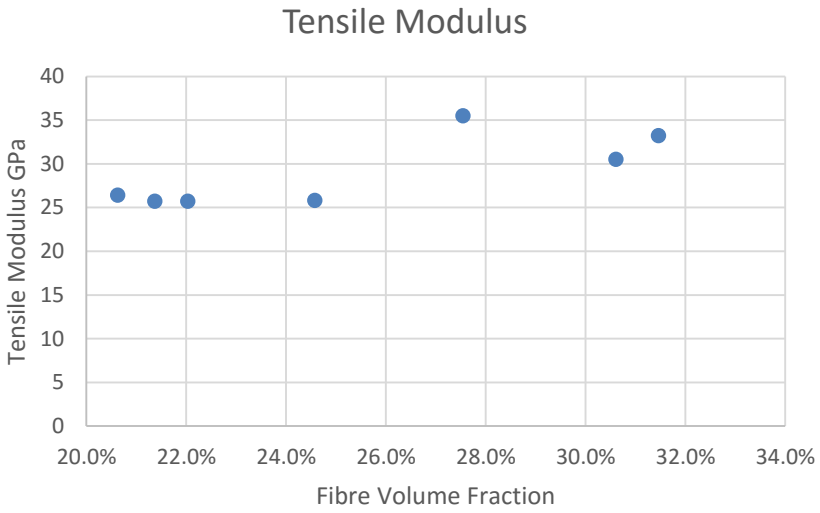
Carbon Fibre Nonwovens

- Different processing characteristics and mechanical properties compared to conventional composite materials.
- Use has been demonstrated in the main processes considered viable for high volume manufacturing: liquid compression moulding, HP-RTM, prepreg compression moulding, SMC.
- First prototype / low volume production projects now underway.
- These projects providing a body of test and processing data that can be shared with other projects.



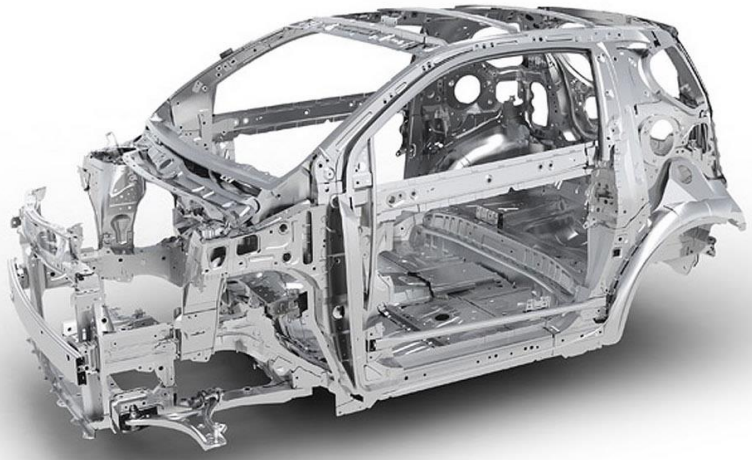
Mechanical Properties of Nonwovens





- Fibre volume fraction typically in the range of 27% to 40% for compression moulding processes.
- Properties dependent on type of feedstock, structure of the nonwoven mat and processing conditions.

Case Study—iStream Carbon



- Conventional stamped steel chassis: Typically hundreds of stamped metal panels.
- iStream hybrid structural composite chassis: Simple, low cost steel tubular members. 14 composite panels.

- iPanels based on recycled carbon fibre cost approximately €30 each, compared to €300 each for panels made from conventional woven fabric prepreg.

iStream photos and information courtesy of Gordon Murray Design Ltd.

What Next?

Current Capacity (Output of Carbon Fibre Products)

- Fibre reclaiming: 1,300 tonnes per year
- Chopping: 1,500 tonnes per year
- Milling: 1,500 tonnes per year
- Nonwoven production: 250 tonnes per year

Pilot Capability

- 2 pilot lines for textile research and development
- 1 pilot line for pellet production (thermoplastic compounds)
- 1 pilot line for impregnated products (prepreg and SMC)

Expansion Plans

- Germany (operational H2 2018): 2,500 tonnes annual output of reclaimed fibres, nonwoven and pellet conversion technologies.
- US (operational H2 2019): 2,500 tonnes annual output of reclaimed fibres, nonwoven and pellet conversion technologies.
- Both plants designed and built to accommodate expansion to 5,000 tonnes per annum output.

Summary

- Carbon fibre recycling has been established at an industrial scale.
- An initial range of products is now available for the compounding composites manufacturing industries—focus on making lightweight affordable.
- QA and QC controls implemented to ensure that the requirements of mass production markets can be met.
- ELG CF R&D programmes are providing the data and performance demonstrator necessary to allow designers to use these materials.
- ELG CF is gearing up for expansion to support the global automotive industry.