

GROWTH OPPORTUNITIES FOR COMPOSITES 2011 - 2023

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Abstract

Our world will consume 43,000 tonnes per year of carbon fibre in 2010. Published forecasts for Carbon Fibre vary, predicted global demand, in 2020 ranges between 240,000-340,000 tonnes per year. These figures are always revised upwards, never downwards as new business is identified. India's markets demand should equate to 37,000 tonnes per year in 2020.

Most Carbon Fibre is manufactured from PAN - an expensive and wasteful process. As fibre demand rises prices need to fall. Our 'eco revolutionary' world needs a sustainable source of high quality Carbon Fibre.

This paper will explore demand, capacities, alternative precursors and novel fibre spinning technologies.

Background

Human population has increased '3 fold' over the past 50 years. Growth is greatest in the emerging world: Asia, Africa, Latin America. Europe by contrast, has remained nearly static. This huge increase in humanity, combined with individual drive to improve personal wealth, is the engine of global economic growth. The global economy has endured a recession caused partly by the imbalance of population growth and associated trade. 'Old' world G8 nations (Europe, USA, Japan) stagnate while 'emerging' nations (India, China) undergo a 21st century industrial revolution. In Japan, 75% of the population is over 30 years old, in India 75% of the population is under 30 years. We have serious trade deficits. Future GDP will be determined not by population growth - but by the ability to cope with over population - food, energy and land shortages.

Climate change - the cost of energy - will drive the next 50 year economic cycle. Our planet has a finite capacity; we need to live within this. People can't change easily; we live in the same houses and drive the same inefficient cars each day. We must change our entire energy structure, decarbonising the world economy - introducing wind energy, nuclear power and low 'mass' transport. California actively promoted 'greening' and is now 40% more energy efficient than a decade ago. Can we apply economic environmental modeling on a continental scale to India and China? We need to provide these nations with high technology alternatives.

The Organisation for Economic Co-operation and Development has just published its latest, twice yearly economic outlook. In 2009 world trade plunged 11%. This year it will grow 10.6%, almost making up the loss in 12 months. In 2011 growth is forecast at 7.3%. There are risks to European/USA sovereign debt markets, and to overheating emerging market economies, but outlook is positive. This will drive up oil prices and growth will moderate.

If we examine the disruptive depression - mid 1920's until mid 1930's - revolutionary materials, processing and products emerged to reignite a new economic cycle (aluminium, electricity, automobiles). Disruptive economics breeds new technology, new revolutionary '2010' materials and products exist.

Air transport is an example of unpredictable change. In a 'perfect storm' scenario, air cargo was enduring a dreadful first half of 2009 with freight traffic falling 25-30%, just as Airbus and Boeing were introducing new - and expensive - cargo wide bodies. The industry lost 5 years growth overnight! Freighters are traditionally converted from 'old' passenger aircraft, a secondhand McDonnell Douglas DC-10 costs \$14m. 13% of the world's large civil aircraft fleet was mothballed by July 2009, 2850 aircrafts. There was no demand for brand new \$200m freighters. 12 months on, recovery has been eye-watering; International Air Transport Association has recorded a global 28.1% rise. Asian carriers are up 35.9% in

the same period. There is an insatiable demand for new fuel efficient Airbus A330-200F freighters over second hand gas guzzlers. When fuel was at \$1 gallon it required an annual utilization of 4000 hours for the A330-200Fs higher capital cost to be offset by its lower operating cost over a DC-10F (a FedEx favourite). Fuel is presently around \$2.90, this utilization is halved to 2000 hour/yr. Average flying time for a wide body freighter is 12 hour/day. There is an instant economic 'flip'. A new energy efficient aircraft is available that allows operators to generate a new economic model. The world freighter fleet is renewing itself as quickly as product can be built. It is all about the price of oil.

A similar scenario is emerging in the passenger business. Singapore Airlines (SIA) has a modern fleet of 11 A380s and ~ 80 Boeing 777s, and is the world's most profitable airline business. British Airways (BA) runs an aging fleet of 300 + aircraft, including ~40 twenty-five year old Boeing 747-400s. SIA is worth 3-4 times the value of BA. The introduction of Boeings B787 Dreamliner will revolutionise the world airline business over the next 8 years.

Anything that moves - wind, automotive or plane - needs energy. Issac Newton told us that "force = mass x acceleration". Reducing mass directly reduces energy required. A new, light weight and very strong material, Carbon fibre reinforced plastic known as composite material, is finding applications in all 'kinetic' systems. 25% (by weight) of an Airbus A330-200 Freighter and 50% of a Boeing B787 are composite. A 20th century definition of an advanced nation has been its ability to refine and manufacture materials - aluminium, polymers and nuclear. Key to composites is Carbon fibre. Perhaps a 21st century definition of an advanced nation is our ability to manufacture high grade Carbon fibre. The Carbon fibre sector has shown recent growth of 25% of CAGR, "It's like silicon valley but with steroids". A significant world shortage is forecast over the next decade.

Carbon Fibre Demand, 2010 - 2020

The world will consume ~ 43,000 T/yr Carbon fibre in 2010. By 2020 we will need ~ 340,000 T/yr. Most Carbon fibre is manufactured from PAN - a wasteful process. The world presently produces about 90,000 T/yr of 'fibre' quality Rayon - PAN precursor. There is no reasonable possibility of increasing capacity to 700,000 T/yr. As

manufacturing capacity rises, prices need to fall. A low cost, high volume, Carbon fibre for new markets needs to be developed. PAN is not 'low' cost. An 'Eco Revolutionary World' needs a sustainable source of high quality fibres. Without this availability global growth will falter. The Victorian industrial revolution was driven by coal, the 20th century driven oil. Our 21st century requires high performance materials - the basic 'building block' for this is Carbon fibre.

Published forecasts for Carbon fibre vary, predicted global demand, in 2020 ranges between 240,000 - 340,000 T/yr. These figures always revise upwards, never downwards, as new businesses are identified. If these estimates are true, Europe's 35% market share in 2020 should equate to ~100,000T/yr. Future Industrial and aerospace projects are known, we can estimate the composite content of each program, and so calculate the Carbon fibre needed. It is more difficult to forecast individual program start dates and build up rates. Technical projects, especially aerospace are notoriously delayed, hence the 240,000 - 340,000 T/yr 'range'. World Carbon fibre usage is split; 20% aerospace, 60 % industrial, 20% sports.

World wind energy installation will exceed 55,000 MW/yr by 2020; Asia is forecast to install 20,500 MW/yr alone in 2020. 55,000 MW/yr equates to installing 65,000 new wind turbines or 200,000 blades every year. 200,000 blades would require 78,000 T/yr Carbon fibre. Toray Ltd. in June 2010 suggested that 130,000 T/yr of Carbon fibre would be required. Large windmills are more efficient than several small ones. Carbon fibre is used in large windmills and glass fibre generally used in small ones. Hence Toray Ltd forecast a significant shift from glass to Carbon fibre usage.

Materials Required for Rotor Blades	World Requirement Ton
Glass fibre	720000
Carbon fibre	78500
Thermoset resins	523000
Core (balsa and foam)	57000
Metal fittings	42000

World sales of 140+ seat commercial jets will exceed 1500/yr by 2020 (sales in 2010 are expected to be ~1100). 1500 aircraft equates to 97,000 tons (empty weight). Since these aircrafts are 50% composite, and composite is ~50% Carbon fibre, then commercial aerospace will need 29,100T/yr Carbon fibre (24,250T + 20% processing wastage).

We can compare the North West region of England, a major civil/ military airframe manufacturing cluster. Total GDP for North West England is \$180bn/yr of which \$13bn/yr is attributed to aerospace. The value of each UK aerospace job is \$134,000/yr - by contrast the value of each job in the UK tourist sector is \$32,000/yr. Similar clusters exist elsewhere in the world - Bordeaux group. The North West of England forecasts it will need 6400 T/yr Carbon fibre by 2020.

In April 2010, BMW Motors announced that they would construct a 4000T/yr (first phase), Carbon fibre PAN carbonising plant, near Seattle, Washington State, USA. Most of this fibre will be shipped to Germany. In

June 2010, Volkswagen declared a requirement for 780T/yr Carbon fibre by 2014, rising to 120,000T/yr in 2022. 120,000 T/yr equates to 20kg Carbon fibre in each new VW (i.e. 40kg of composite). VW envisage that most pressure vessels, liquid and gas, will be Carbon fibre composite. Fuel efficient and high performance cars will feature composite body panels. VW procurement predicts that it will be the 4th largest automotive Carbon fibre consumer, BMW being 2nd. VW require a medium quality Carbon fibre at \$10/kg. They suggest an alternative to PAN and have been experimenting with Polydefin. VW have successfully carbonised Polydefin fibre using a plasma/microwave technique.

The world presently manufactures in the region of 60 million cars per year, this will grow to more than 75 million by 2022. BMW/VW's model suggests that the auto industry will require 1.5 million T/yr of Carbon fibre! This 'parabolic' profile is difficult to grasp, though it is similar to previous demand curves for modern metals and polymers.

Table-2 : Estimated Carbon Fibre Demand (Tonnes) 2006-2020

	Global Demand			
	2006	2010	Confirmed Scenario	'Risk' Scenario
Civil Aviation				
Existing Aircraft (A320, B777 etc)	3700	5200	3400	2000
B747 Replacement				2600
B777 Replacement				6000
A380	200	2000	2000	2200
A350	-	-	2700	8500
B787	100	3000	6000	6000
New B737 and A32X	-	-	15000	15000
Military				
Fighters, Transport, Helicopters	900	1250	1800	3600
Regional Aircraft and Business Jets	230	488	625	1200
Total	5130	11938	31525	47100
Wind Energy	3750	7500	78000	130000
Sports	5420	6660	8330	9000
Industrial (including gas tanks)	9860	14560	25830	34000
Other uses (including anti-ballistic and medical)	1000	1000	1000	2000
Automotive	1800	2100	96000	120000
Grand Total	26960	43758	240685	342100

Discussion

We must understand how to manufacture large quantities of high quality, low cost, Carbon fibre. A new range of Carbon fibre with various surface properties is needed ('fat' Carbon fibre, surface coatings, wetting fibres). Oxidising Carbon fibre after its UHT treatment will roughen its surface enhancing matrix bonding - improving composite compressive properties.

Composites are fatigue sensitive, consequently components are subjected to multiple NDT inspection. In the aircraft industry 100% of composites parts are inspected. Each part is typically inspected 6 times during manufacture and assembly i.e. 600% inspection. The problem in seeking innovative manufacturing of composites is not whether we should use autoclaves or out-of-autoclave but rather we need a more 'tolerant' composite matrix material. This can be likened to metals - a low strength aluminium 'casting' alloy has a tolerable defect size of 100 microns. Consequently defects are 'easy' to see, measure and control - we can achieve 6 sigma quality. However,

increasing aluminium tensile strength decreases defect size towards 10 microns, making defects more likely, 3 sigma. In the world of C composites we are closer to 3 sigma, but need to move to 6 sigma if C composites are going to be produced at reasonable price for the mass market. We must research tolerant materials, develop flexible fibres that are ductile and can be woven. A crack stopping matrix. Perhaps a binary matrix.

Conclusion

Reduce energy required to manufacture Carbon fibre. PAN has a 50% wastage. A possible replacement for PAN might be polyparaphenyline. Develop hybrid fibres / binary fibres that translate toughness or could be used in novel matrices. Radical spinning techniques - laser spinning / melt spinning / Sol Gel / pitch. Growing an organic source that can be oxidised and carburized. Polydefin - can we straighten, plasma process and microwave these fibres. New matrices (molecular wt. vs. toughness / functionality / optimisation DAMS - amino function system).

India's Largest Indigenous Autoclave for Processing Airworthy Composites

CSIR-National Aerospace Laboratories (NAL), Bangalore has successfully designed, built and commissioned India's largest Autoclave in the Aerospace Sector. It has a working space of 4.4 m dia x 9 m length, operating temperature and pressure of 250°C and 7 bar respectively. The main design drivers are Simplicity, Fail-Safe and Fault-tolerant features and easy maintainability.

The Salient features include :

- * Davit arm door with lock ring less quick lock mechanism.
- * Steering mechanism with minimal space for door parking.
- * An innovative cooling system with variable heat transfer area.
- * Pressurised Blower Motor.
- * An efficient Air Circulation System (+/- 1 deg C temp. uniformity)
- * Integrated Nitrogen generation Plant to create inert atmosphere.
- * An advanced dual computer with in-house built software for effecting cure control.

The Autoclave is currently used for processing large size airworthy advanced composite components such as wing, fin, empennage, fuselage parts, etc for the NAL/CSIR Civil Aircraft, 'SARAS'. It also incorporates several fool proof safety and reliability features.