The first use of carbon fibers in industrial scale was in electric light bulbs. Precondition for this application had been the invention of the dynamo-electrical principle by Werner von Siemens in the year 1866. The subsequent installation of electrical grids made electricity available for everybody. Edison experimented with many different fiberous organic precursors which he gathered from all over the world, until he found a bamboo which gave the carbonised fiber the sufficient stability. This carbon fiber, enclosed in an evacuated bulb and heated by the electric current provided a constant, bright and enjoyable illumination compared what humans had used before. Consequently this light bulb became an industrial success. In particular in Germany the entrepreneurs Emil Rathenau licensed 1882 the patent from Edison and started with Werner von Siemens the electrical illumination of Berlin. Rathenau founded 1886 the Allgemeine Elektrizitäts Gesellschaft (AEG) which lasted until 1996 (Fig.1).

The use in light bulbs remained the solely application of a carbonised organic fiber for a long time. Not until the 1950 the interest in carbon fibers raised again with focus on their excellent mechanical properties at light weight. The first precursor used for the production of carbon fibers was a semi-natural cellulose fiber, Rayon. A few years later the advantage of polyacrylonitril (PAN) fiber superseded Rayon and became the dominating precursor fiber for the production of carbon fibers. The later developed and commercialised pitch based carbon fibers remained a niche product for applications were extreme stiffness is required. The strength and stiffness areas for the various types of carbon fibers are summarized in Fig.2. The biggest market with future relevance has the high tenacity (HT) fiber in large tow size (> 24 K). Today high-end HT C-fiber types are predominantly used in the aviation industry with small tow sizes (1–6 K).

1. Introduction

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Whereas the fundamentals of PAN based carbon fibres had been developed in the UK, the commercialization and further development took place in the U.S.A. and Japan. The total PAN-based carbon fiber nameplate capacity in 2008 was 68000 t. Thereof about 60% belongs to companies with their home-base located in Asia, preferentially Japan (Fig.3). The second position is held by U.S.A. home based manufacturer like Zoltek, Hexel and Cytec. SGL Group- The Carbon Company is the only producer with its home-base in Europe (Fig.3).

Both big Japanese carbon fiber producers are operating subsidiaries in Europe as well as in the U.S.A. The North American market demand is covered by home-based and foreign based manufacturing capacities. The capacity of the Asian market is bigger than its own demand. The European market has a minor home based capacity and even the foreign capacity operated in Europe is not sufficient to cover the European demand. This gap has to be compensated by imports from Asia and the U.S.A. (Fig.4). Europe although being the biggest user market for carbon fibers has missed to build up its own home-based supply.

Most crucial for the production of carbon fibers is the availability of the adequate PAN precursor material. The production of this special precursor has similarities to a textile PAN fiber only in its fundamentals. Moreover this precursor production requires particular attention in its chemical composition, purity, spinning, coagulation and textile production parameters. This knowledge is the proprietary of each producer and not accessible to the public. Consequently each established carbon fiber producer had developed its own precursor know-how and production. When we look at this situation on a global basis the satellization of Europe and the U.S.A. from Asia / Japan can be described as dramatic (Fig.5).

### 2. Carbon Fiber Market

The drivers for the early carbon fiber market had been military applications followed by requirements from space activities. Later carbon fibers were adopted by the sport industry. High fiber prices and labour intensive production limited the wide penetration into mass markets like the automotive industry. This situation goes back more than 30 years. Energy was cheap and the availability of oil considered as mostly “endless”. This situation has changed dramatically. The oil price had reached 140$/$b in 2008 and the
peak oil became common sense. The climate debate has discredited CO₂ and the production of energy from fossil fuels. Alternative energies, energy efficiency and energy savings became mega-trends. Combustion engine powered mobility will on a long to midterm basis have to compete with electromobility. All this provides spectacular opportunities for carbon fibres to enter into mass markets like civil aviation, wind power generation, automotives, and civil engineering (Fig.6).

The growth in the carbon fiber market will be driven by industrial applications, followed by the aviation industry. The carbon fiber capacity expansion installed in the years before 2008 led to an overcapacity which was enhanced by the financial crisis in 2009. This overcapacity will be compensated by the growing demand for carbon fibers by 2015 latest (Fig.7).

4. Carbon Fiber Cost

Carbon fibers are a high cost material and a cost reduction was always discussed as the necessary precondition to enter mass markets. Is a cost reduction of PAN based carbon fibres realistic? The cost structure of carbon fibers is dominated by the precursor cost with close to 50%. This raw material cost depend on the crude oil pricing which is not expected to once return to historical lows of 20 – 30 $/barrel. The second position is hold with about 20% by energy cost. Energy saving are possible to a limited amount but may be compensated by increasing prices for energy. In total cost for the production of PAN based carbon fibres will rather show an increase then a decrease (Fig.8).

The big potential for cost reduction lays in the production of the carbon fiber reinforced composite (CFRP). The use of high filament towels offers dramatic cost advantage versus low filament towels. Needless to say is that this requires the development and installation of new textile manufacturing techniques. Highly automated textile techniques will increase the productivity, at high repeatability of quality of components, reduce in-process inspection cost and enhance the carbon fiber and resin utilization rate (Fig.9).

Additional cost reduction potential is seen in the introduction of thermoplastic resins. The unit labor cost can be reduced dramatically. Former manual lay-down rates in the aviation industry of 2 – 4 lbs/hour have reached 30 lbs/hour. Projected lay-down rates are 200 to 500 lbs/hour.

An impression how such a modern, highly automated production looks is shown in Fig.10.

The nose and cockpit section of Boeing’s Dreamliner is formed by the automated winding of carbon fiber tapes on a mold. The
whole operation needs few technicians only.

With such new textile techniques the aviation industry has increased the content of CFRP composites in airplanes to above 50\% (Fig.11).

Due to this enormous importance of CFRP in today’s aircraft manufacturing the market leaders Boing and Airbus entered into strategic supply contracts with carbon fiber manufacturers. In 2006 Boing and Toray signed a supply contract for the Boing Dreamliner with a 3–6 bn $ volume. Two years later, in 2008 Airbus Industries and Hexcel agreed on a contract volume of 4–5 bn $ for the Airbus 350-XWB.

The solely home-based carbon fiber producer in Germany is the SGL Group. Following a consequent strategic vision SGL settled its position in the traditional carbon and graphite market by several mergers and acquisitions. The sound position in this market provides the financial backing to expand into the growing field of carbon fibers and CFRP (Fig.12). The carbon fiber and composite market is one of the most attractive one’s due to the high growth rates in the industrial and aviation industry sectors.

SGL strengthened its core business Carbon fibers and prepregs / preforms by the upstream integration With EPG, a joint venture with Lenzing, SGL integrated its own precursor fiber production. The joint venture with Mitsubishi Rayon on precursor fibers serves the traditional C-fiber business and also the joint venture with BMW for the production of the Mega City Vehicle (MCV). The C-fibers for the MCV project will be produced in the USA at Washington State due to attractive energy contracts and energy from hydropower. This provides a low CO₂ footprint for the C-fiber. This C-fiber plant was finished in May 2011 after only 9 month of construction. The C-fiber capacity will be 3000 t provided by two lines with 1500 t each. Prepregs and preforms will be provided for the MCV project by a joint venture between SGL and BMW, Automotive Carbon Fibers (ACF), located in the south of Germany.

SGL Kümpers, EADS-IW and Airbus Operations developed a highly automated braiding system for the production of complex airplane structures. They received for this development the JEC Innovation Award 2010 (Fig.13). Benteler SGL constructs and produces CFRP parts for the automotive industry. The acquisition of Rotec a wind mill producer takes into account the increasing demand for C-fibers for wind power plants in off shore areas.

HITCO in California serves the aviation and defense market. To successfully implement carbon fibers and CFRP in the market it is necessary to cooperate within the supply chain of the interested industries. This comprehends the improvement and development of textile processes, development of new resin systems, forming devices, measurements- and quality systems and many other issues. Last but not least the lobbying of the joint interest versus local and European authorities is of importance. For this purpose a Carbon Composite Association was founded which comprises today about 140 members. Members are the leading companies in the automotive (Audi, BMW, Daimler), aviation (Eurocopter, MT Aerospace, EADS) and robot (KUKA, Siemens) industry, all located in the southern part of Germany with short distanced to each other. The industrial field is completed with a strong academic support in the
same area (Technical University Munich, University of Augsburg, DLR Centre for light weight construction in Augsburg, Fraunhofer in Augsburg).

These excellent frame conditions will bring Germany into a new and competitive position in the area of carbon fibers and their related composites.

Remarks
Market figures are updated, status May 2011.

References
2) City of Berlin.