

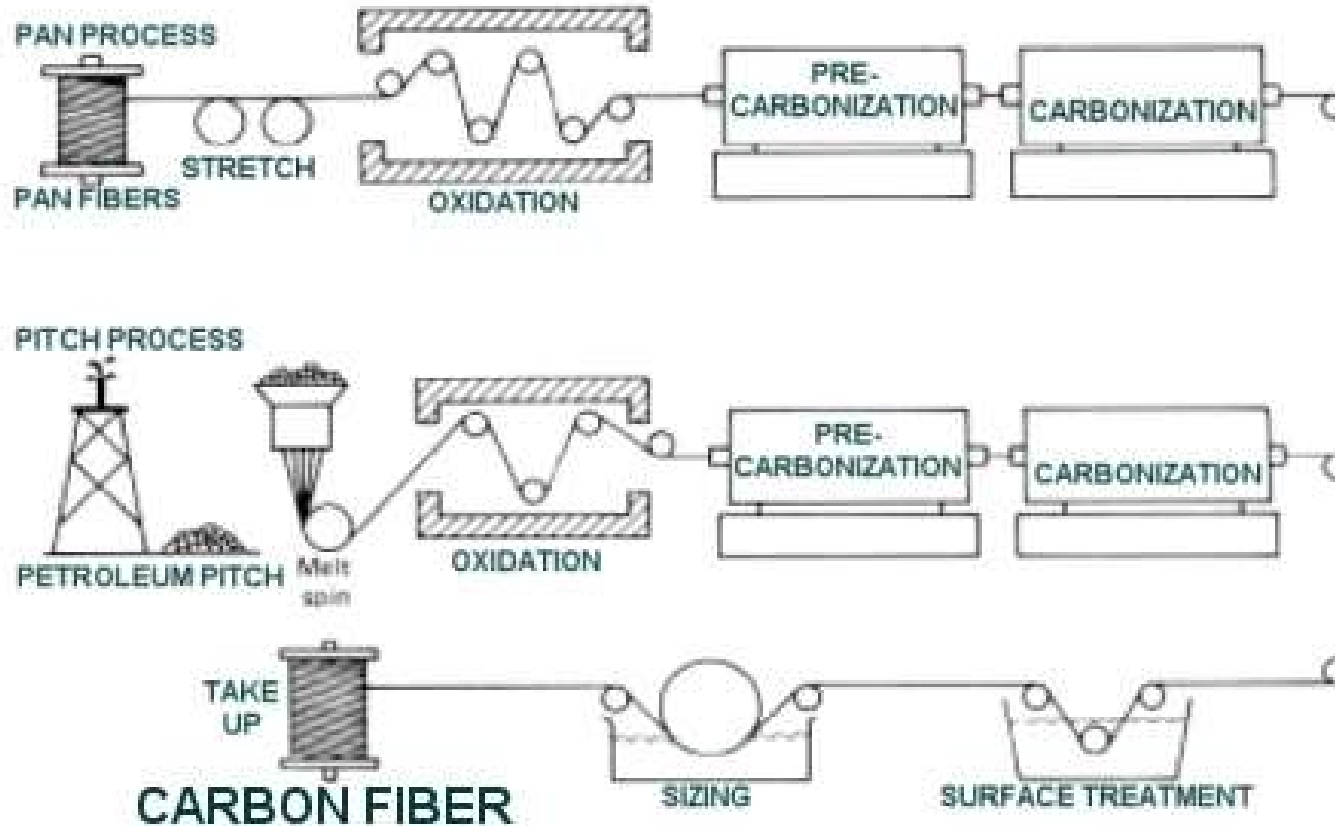
Energy Costs in Carbon Fiber Production



Contents

1. Types of carbon fiber (Pitch and PAN Precursor Materials)
2. Outline of the PAN based carbon fiber process
3. Grades of PAN based carbon fiber
4. Stages of the carbon fiber process,
5. Summary of energy requirements for pilot and production line.
6. To conclude.

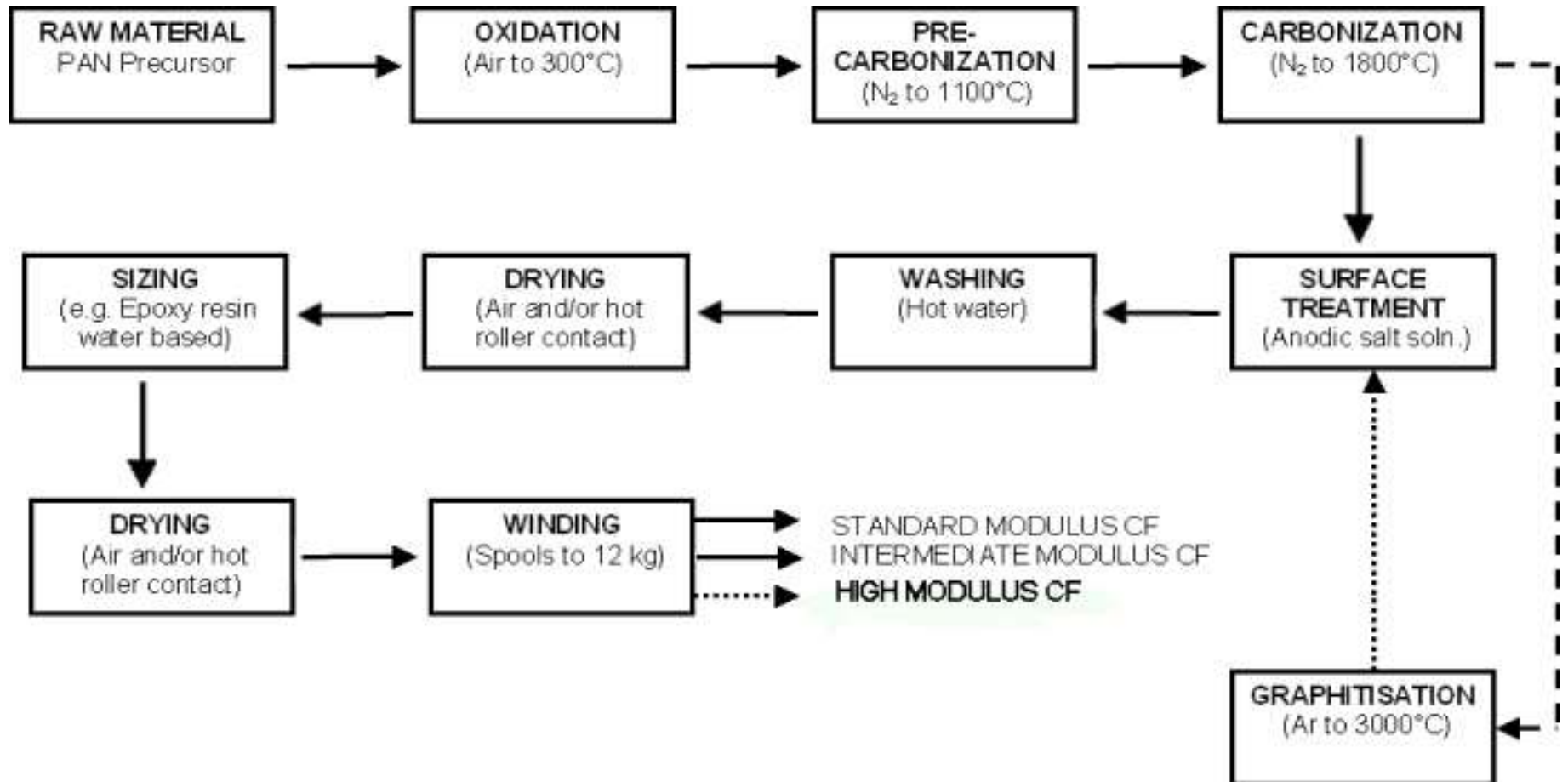
Types of carbon fiber (Pitch and PAN Precursor Materials)



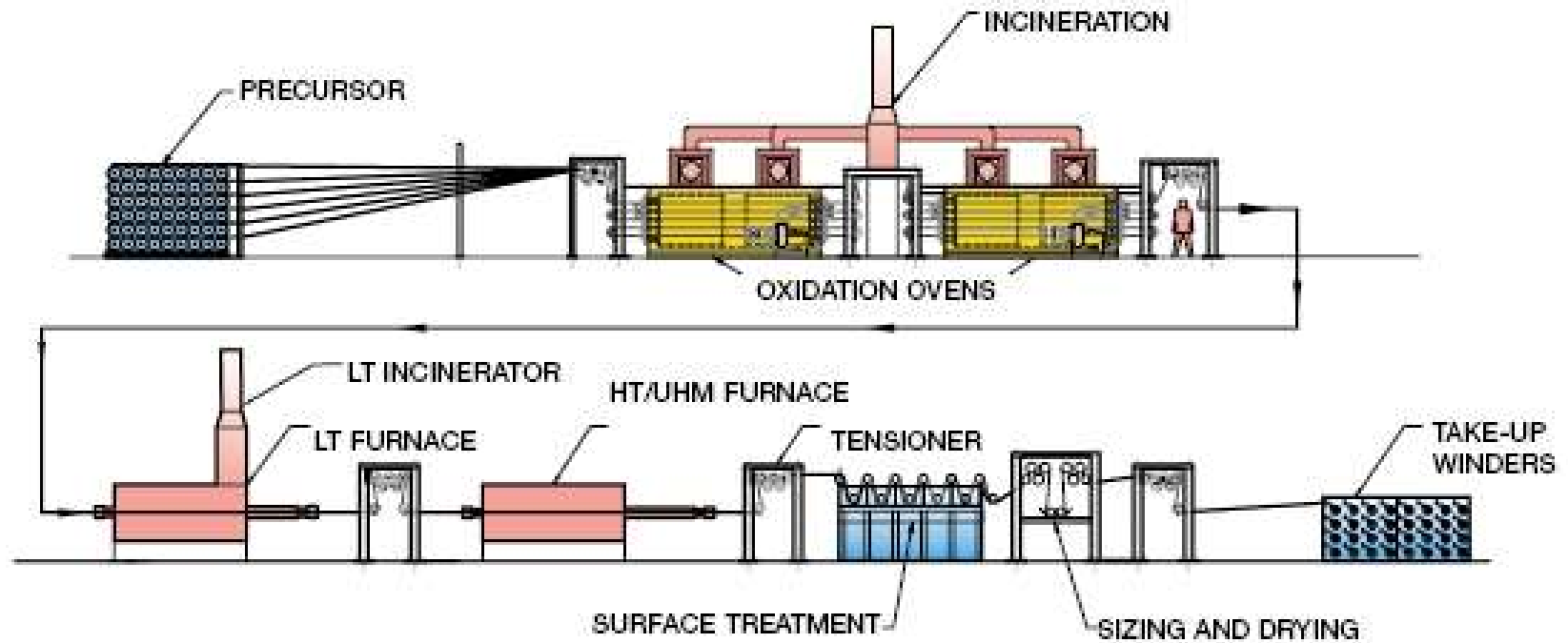
Pitch = cheap, lower tensile strength

PAN= more expensive, superior properties

Outline of the PAN based carbon fiber process



Outline of the PAN based carbon fiber process



Outline of the PAN based carbon fiber process



- Outline of the PAN based carbon fiber process



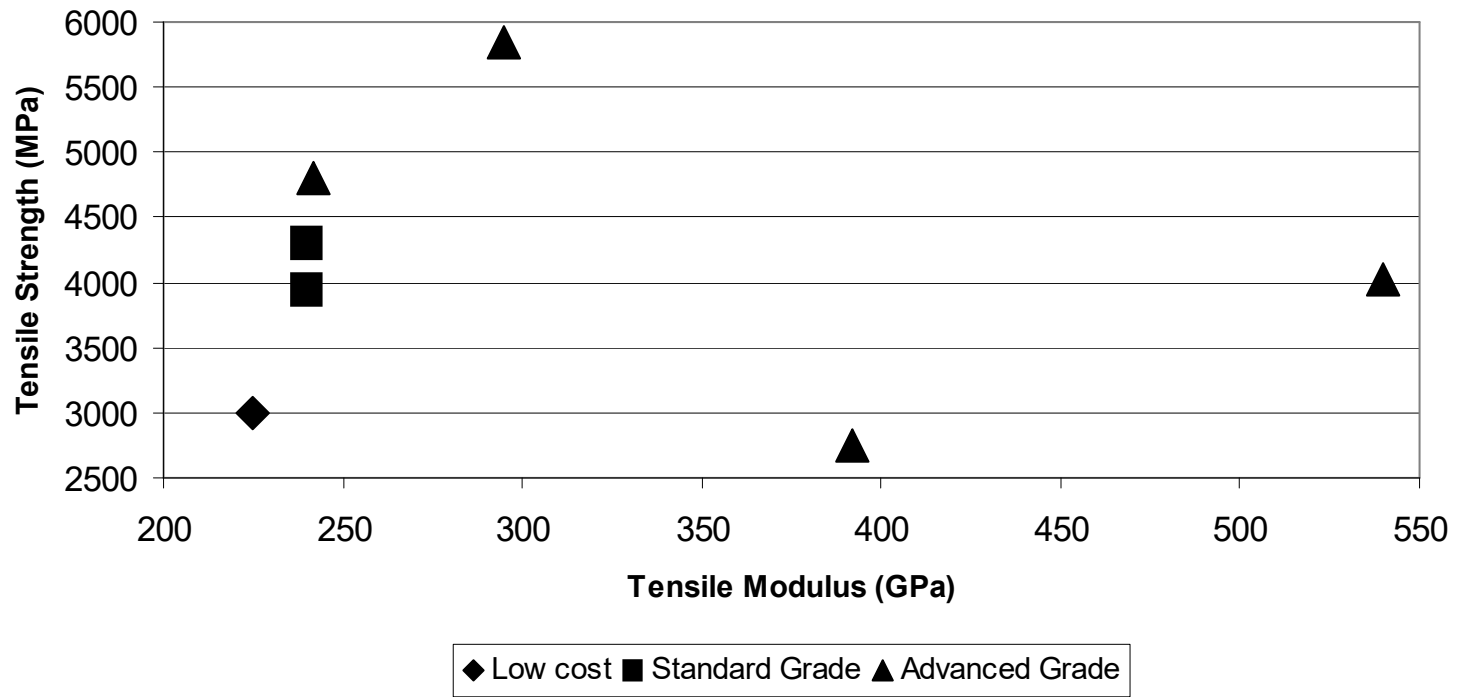
—————→ Running direction



Grades of PAN based carbon fiber

Mechanical Properties

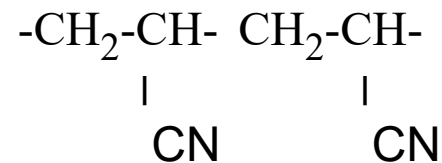
Mechanical Properties of PAN based Carbon Fibers



Stages of the carbon fiber process

Precursor

RAW MATERIAL
PAN Precursor

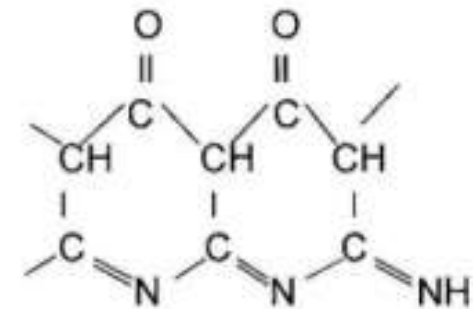
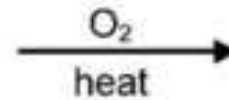
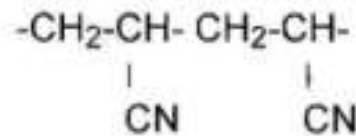


- Specially developed PAN (**P**oly**A**crylo**N**itrile) fibers for the carbon fiber industry, using traditional technologies of acrylic textile fiber manufacture.
- Most carbon fiber companies manufacture their own precursor, using in house technologies. Variables include type of solvent, type and amounts of co-monomers, degrees of fiber shrinkage and stretching in the manufacturing process.
- For high performance carbon fibers, the fibers are collected in bundles of 1000 (1K) to 24000 (24K) filaments. The bundle of filaments is commonly referred to as a “tow”.
- PAN tows are usually supplied on spools of up to 50kg weight. These are placed on a precision creel to allow one tow to run next to another to make a towband or sheet of tows, which are transported through the carbon fiber process.
- For the manufacture of lower grade carbon fiber, some commercial textile acrylic fibers are supplied in boxes of up to 300kg weight. These contain a continuous crimped sheet of up to 350000 filaments. Several of these “heavy tows” are transported together through the carbon fiber process in a towband. Not all commercial textile acrylic fibers are suitable for conversion to carbon fiber.

Stages of the carbon fiber process

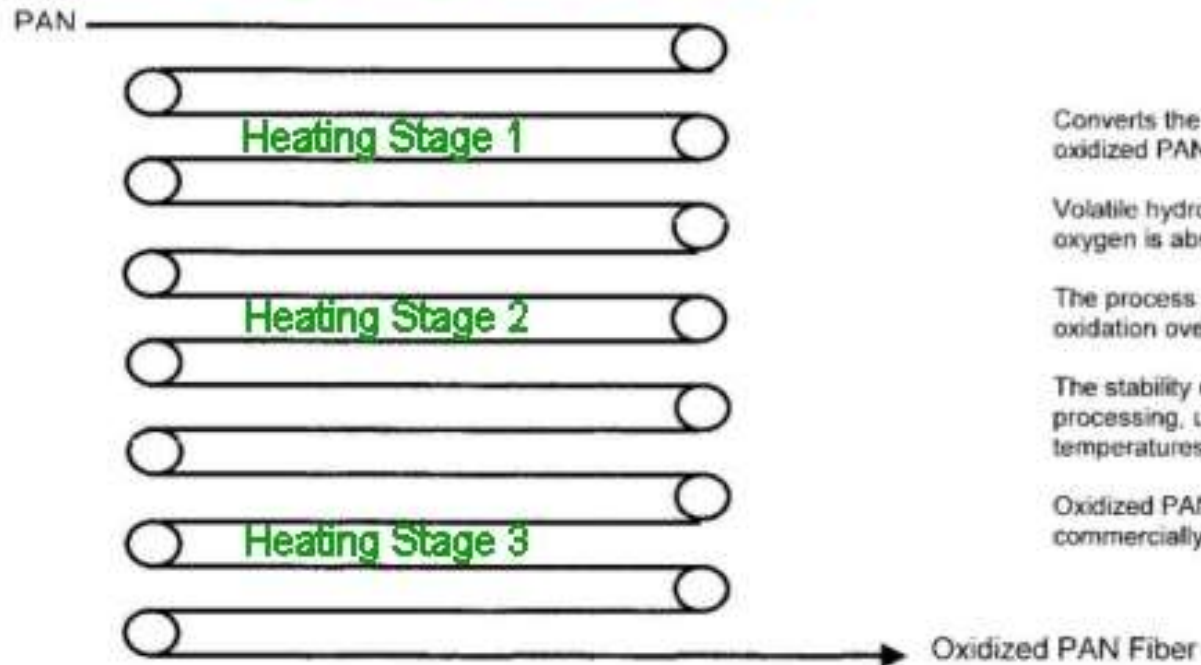
Oxidation

OXIDATION
(Air to 300°C)



+HCN, CO₂, Δheat

Multi Heating 3 Stage Oxidation Oven



Converts the molecular PAN ladder, to the stable oxidized PAN ring structure.

Volatile hydrogen is evolved and less volatile oxygen is absorbed into the ring structure.

The process is extremely exothermic, fires in oxidation ovens are not uncommon.

The stability of the fiber allows further processing, under Nitrogen to higher temperatures.

Oxidized PAN is flameproof and is produced commercially as a fire resistant textile fiber.

Stages of the carbon fiber process

Oxidation Plants

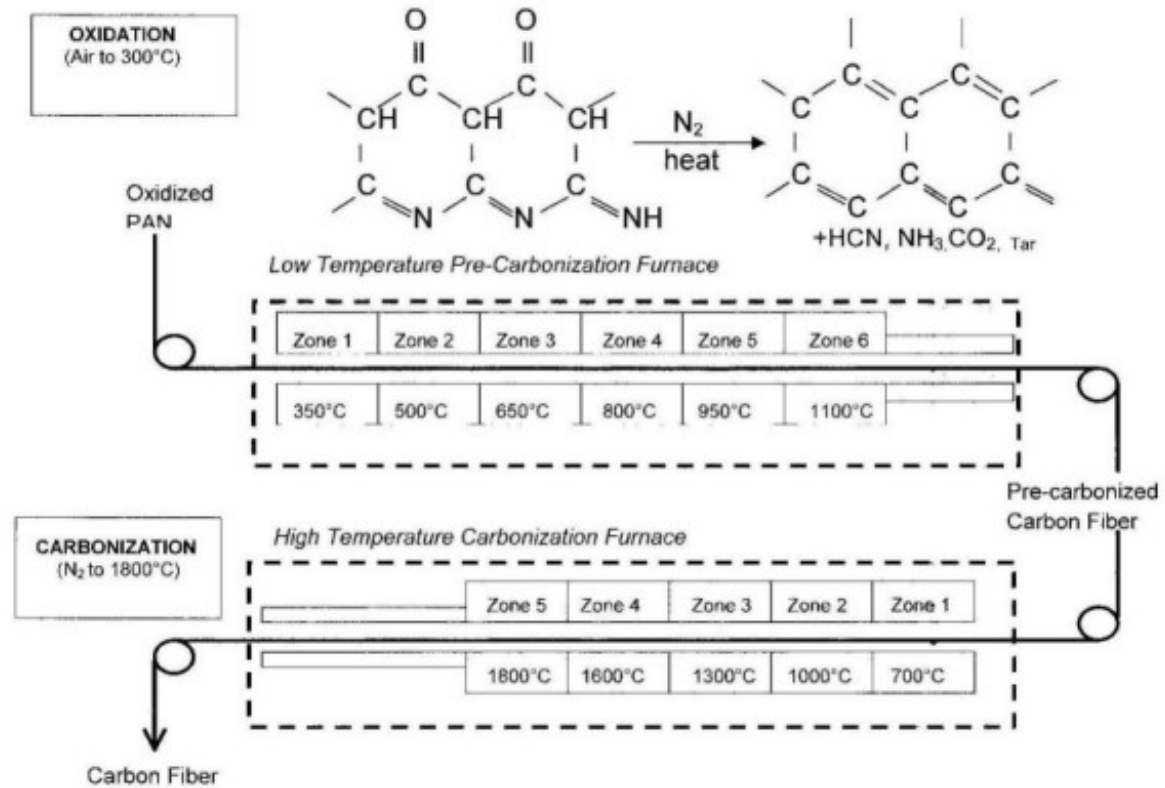
OXIDATION
(Air to 300°C)



PANOX
PANOX[®] is a registered trademark of
RK Textiles Composite Fibres Ltd, Stockport,
England, and is protected by British and Foreign
patents.

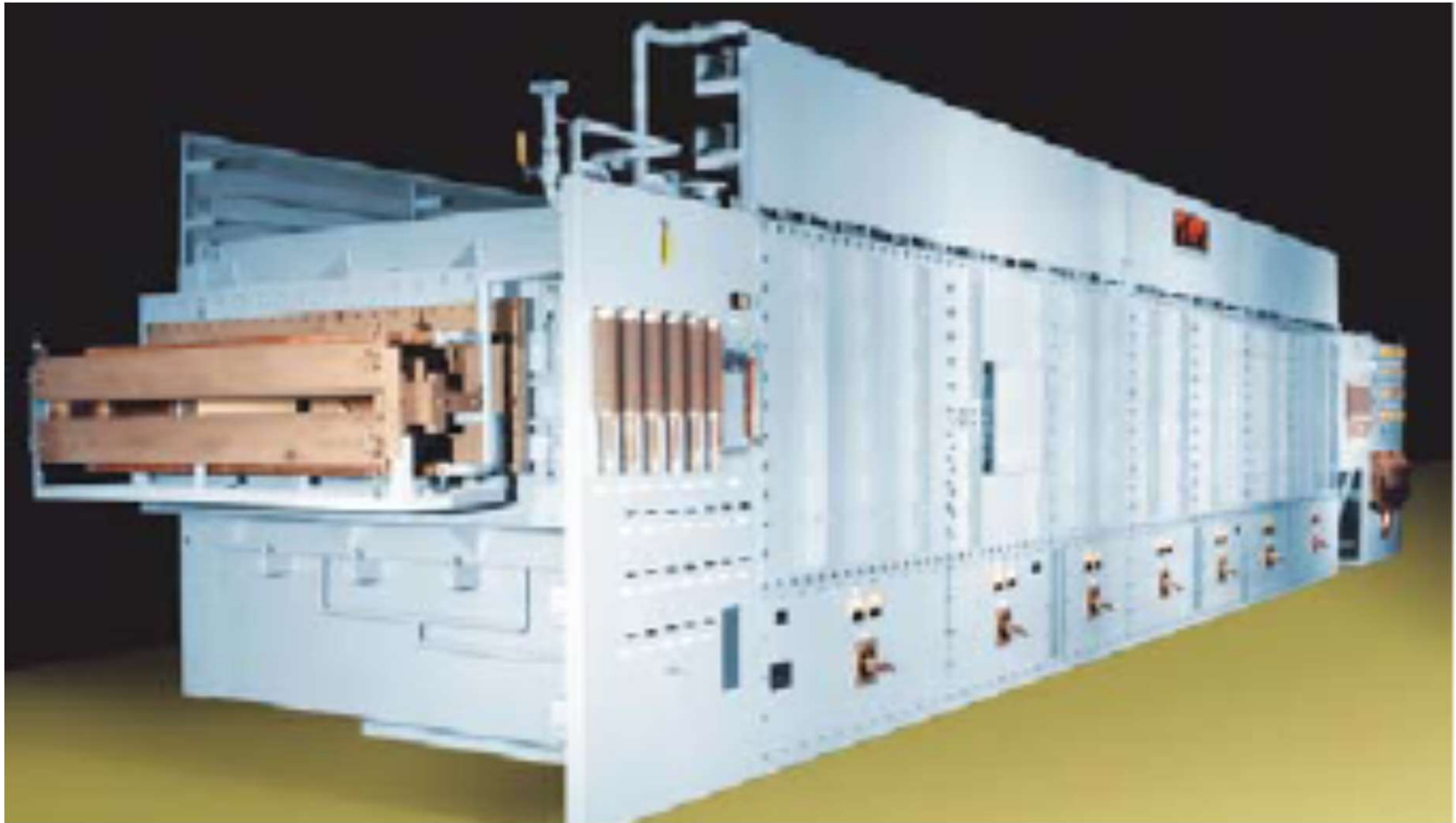
Stages of the carbon fiber process

Carbonization



Stages of the carbon fiber process

Carbonization Plant



Stages of the carbon fiber process

Carbonization Plant

PRE-CARBONIZATION (N₂ to 1100°C)

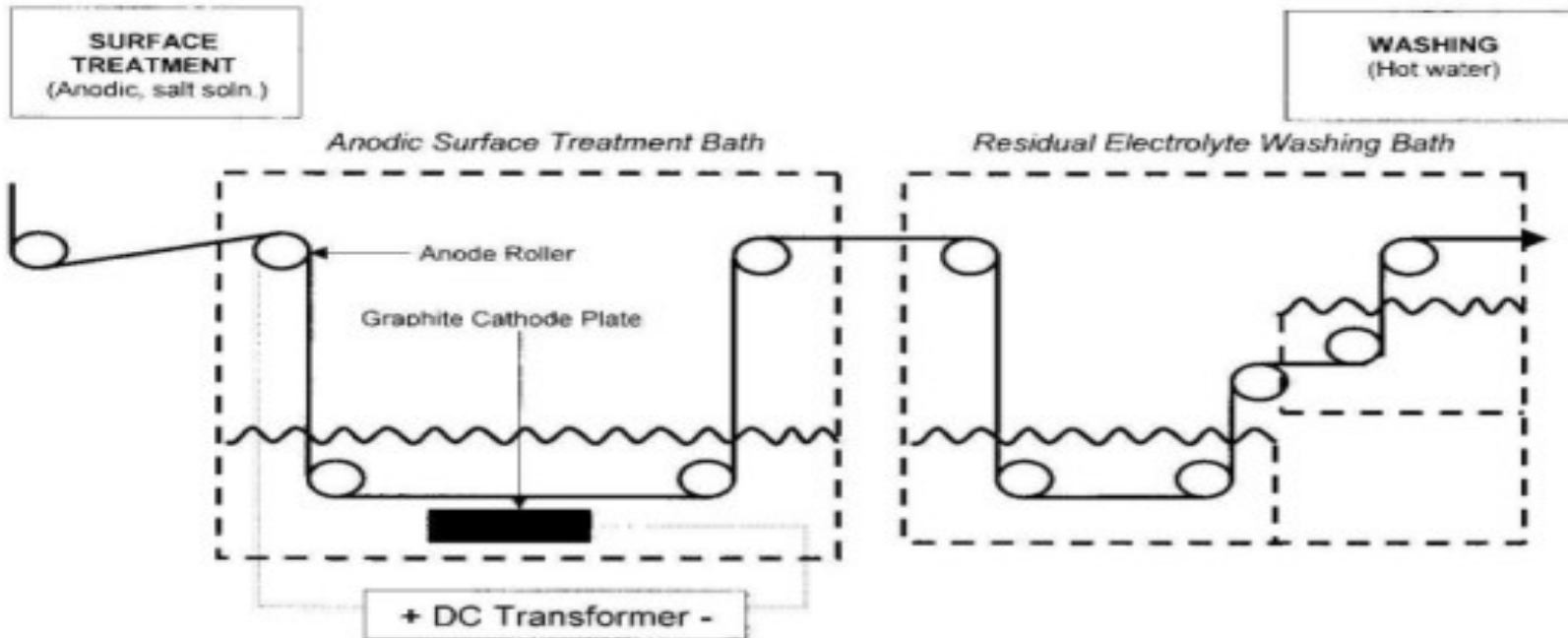
- Oxidized PAN fiber pass through the metal muffle of a furnace, multi-zone heated up to 1100°C.
- Weight loss of up to 50% of the ingoing fiber occurs. The gasses evolved are mainly compounds of cyanide, which forms tarry gasses, which are incinerated directly after exhaust from the furnace.
- Roller drives before and after furnace enable a specific, stretch or shrinkage to be set in the process.

CARBONIZATION (N₂ to 1800°C)

- The product exiting the pre-carbonization furnace is a low quality carbon fiber. Further processing in the carbonization furnace, induce the properties of strength, modulus, electrical conductivity and fiber density.
- Pre-carbonized fiber pass through the graphite muffle of a furnace, multi-zone heated up to 1800°C. The conditions in the (pre) carbonization process can be varied for the manufacture of high strength and intermediate modulus carbon fiber.
- For high modulus carbon fiber a third heat treatment in Argon up to 3000°C is used.

Stages of the carbon fiber process

Surface Treatment/Washing

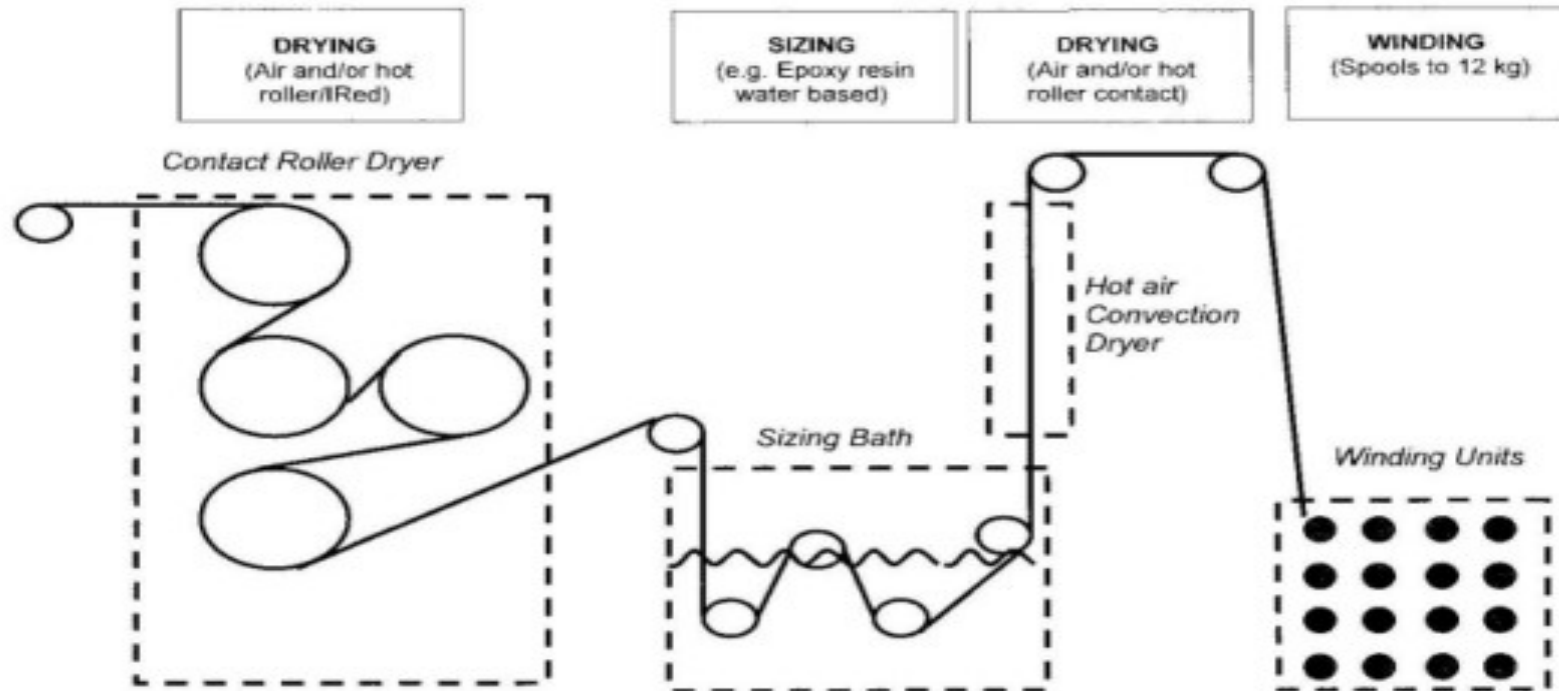


- The electrically conductive carbon fibers become the anode in electrolysis in a salt solution such as ammonium sulfate.
- This causes carboxyl groups such as COOH to form on the smooth fiber surface.
- The carboxyl groups improve the cohesion between the fiber and the resin used in the final composite.

- After surface treatment excess electrolyte is removed by a warm water wash treatment.
- The carbon fiber strands pass through one or more dip baths, with counter current water flow.

Stages of the carbon fiber process

Sizing/ Winding



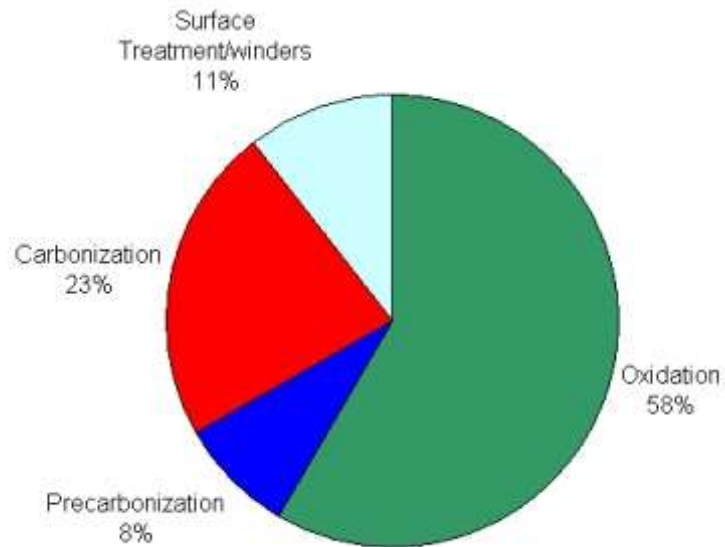
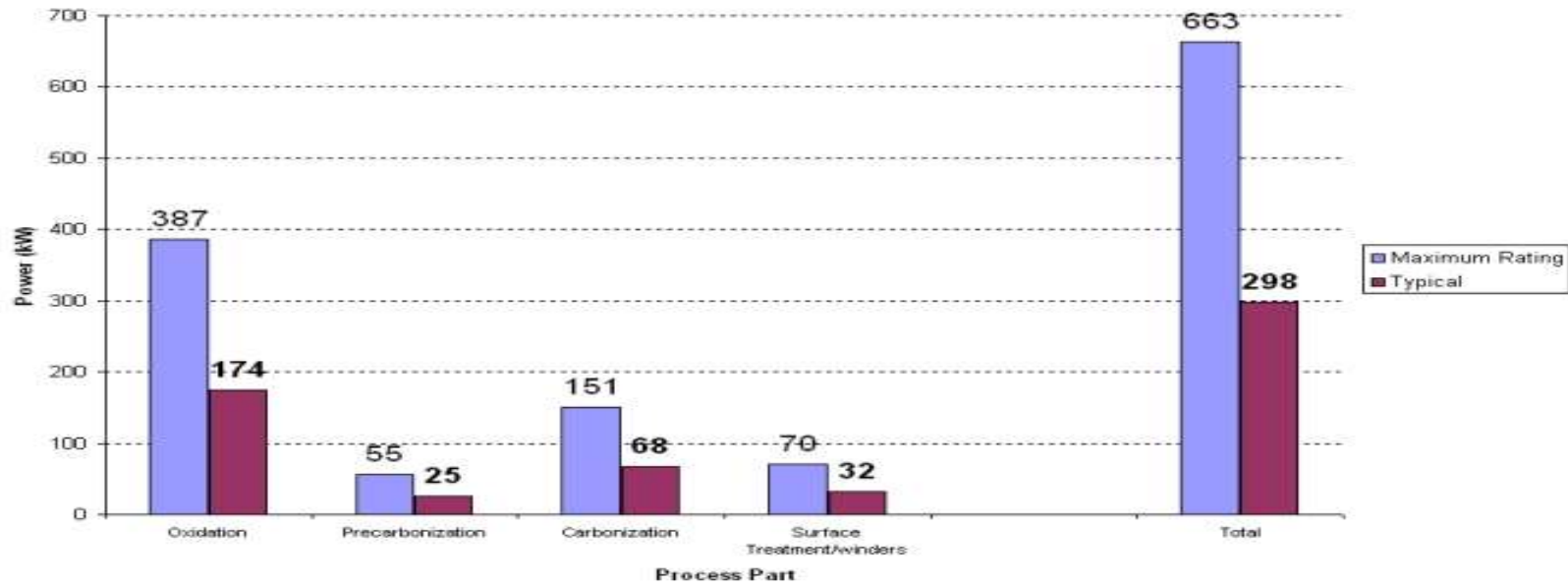
- Carbon fiber strands are pre-dried prior to sizing. This helps ensure a uniform "pick up" of sizing.
- A typical sizing is a dispersion of water and small epoxy particles. The water is dried off, to leave the filaments coated in an epoxy film. This enables ease of handling during further processing of the fiber (e.g. prepregging). Non, and modified epoxy sizings are available for specialist applications. Winders can produce finished spools of up to 12 kg in weight.

Stages of the carbon fiber process

Winding Units



**Pilot Plant
25 Tonnes per Year of 6K**



200 TPA production line in China (PRC)

Carbon fibre: a new player enters the scene

Sometime in April 2005, a polyacrylonitrile and carbon-fibre production plant will start up at Benghu, in the Anhui province in Eastern China – a big first, because carbon-fibre production sites in China have never before produced their own polyacrylonitrile precursor.

The project that China Worldbest Group Co. (CWGC) started about ten years ago is coming to an end. CWGC is a group of companies that specialize in life sciences, textiles and logistics. With 34 subsidiaries and affiliates in China and overseas, including four publicly-owned companies, the group boasts world-class equipment, technology and management.

An instructive preliminary project

"The fact that the project stretched on for nearly ten years, from the initial discussions to the final start-up of the plant, will have been the main difficulty we've had to deal with in this company," confided Mr. Wang Gang, the general manager for Anhui Huawan Carbon Fiber Co (a subsidiary of the

Shanghai Worldbest Investment Development Co, of the CWGC group, and China's leading carbon-fibre producer), during our interview. Another problem is that it was the first of its kind in China. Mr. Gang, who has been with the project from the beginning, is also in charge of future developments. Another big problem was to find a technology. The carbon-fibre market, and more specifically polyacrylonitrile (PAN), is very closed – there are very few players, and know-how is jealously watched over. To set up its project, CWGC signed an agreement in July 2003. The agreement, worth US\$25 million, is with AMEC, an international engineering services firm that works with Applied Composite Engineering Ltd. AMEC is the technical partner for the project. According to them, the plant will produce "polyacry-

lonitrile precursor, which is then converted into carbon-fibre yarn. The plant comprises raw-material storage and preparation, and batch polymerization processing by the conversion of acrylonitrile monomer into polyacrylonitrile. The polymerized product is spun into a yarn and further processed, and then dried to form PAN precursor. The PAN fibre is collected onto bobbins and further processed by the application of increased levels of heating in a controlled atmosphere to form the final carbon-fibre product."

Anhui Huawan Carbon Fiber Co will be China's first PAN producer. In the initial stage of the project, the objective is set at 200 tons of carbon fibre and 500 tons of Protonema. The site is also scheduled to produce prepreg material.

Mr. Gang told us that the carbon fibre produced at Benghu is type 12K, destined for the basic needs of local markets.

He went on to point out that "although no contract has been signed yet, we have established a large number of contacts," and specified that "for the time being, our two main objectives are to control production and lower production costs." About a hundred qualified people have been hired to carry out production.

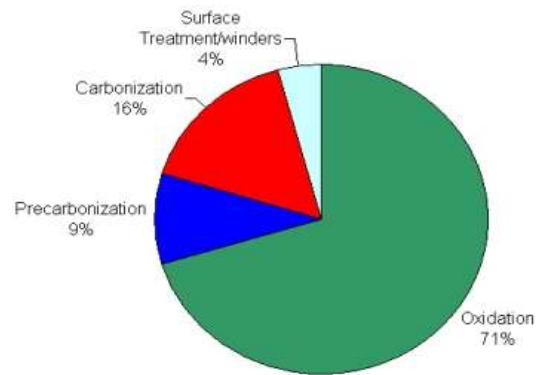
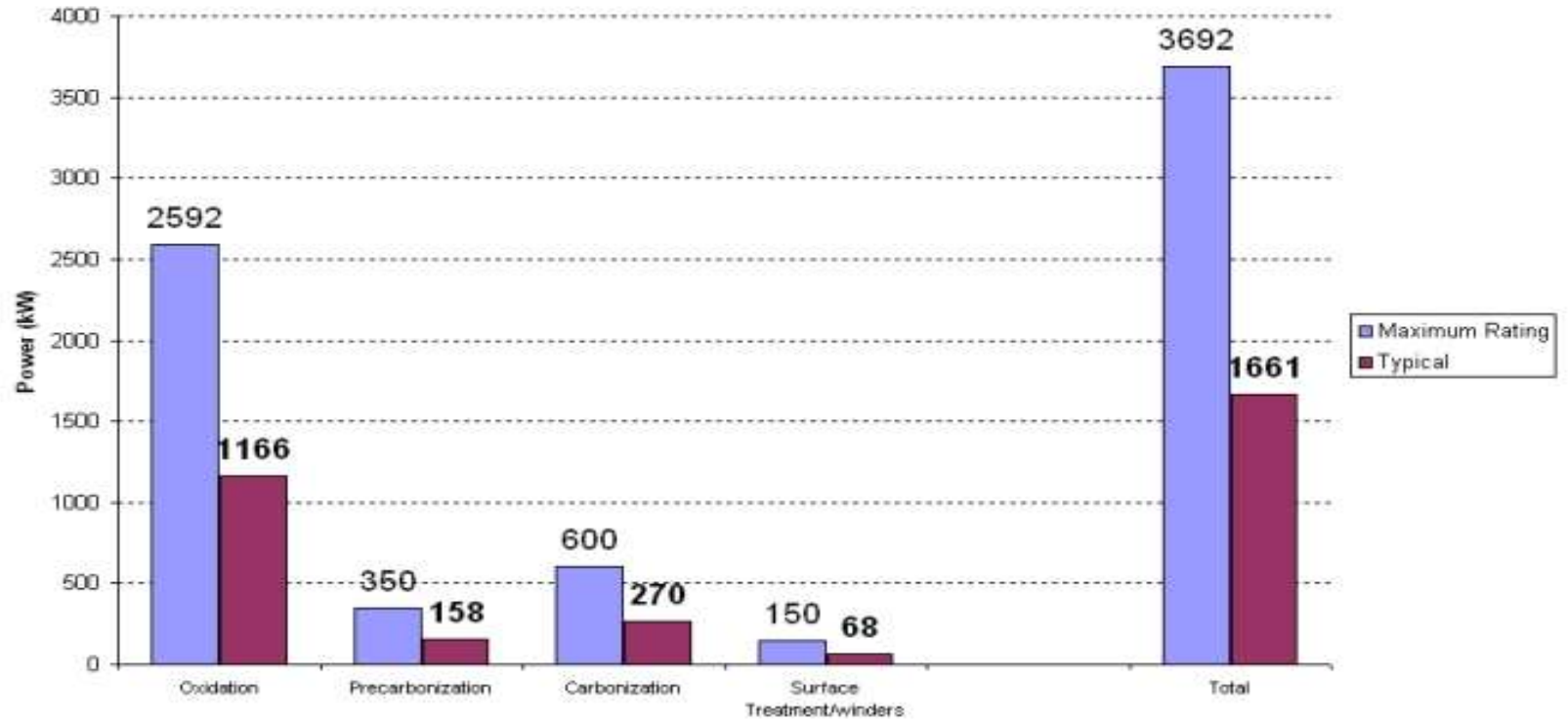
A booming market

The investment is the result of an active market and increasing demand for carbon fibre. The Chinese market has continued to open up, boosting the consumption of carbon fibre in China from 580 tons in 1996 to 1,200 tons in 2000, and more



Mr. Wang Gang, general manager for Anhui Huawan Carbon Fiber Co and head of the project, and Ms. Xie Hai Chan, chief economist at Shanghai Worldbest Investment Development Co – a division of CWGC – which is financing the project.

Production Plant
200 Tonnes per Year of 12K



To Conclude

- The oxidation part of the process use the most energy.
- Low cost (heavy tow) manufacture is more efficient than small tow manufacture because more fibers can be loaded into the oxidation.
- Newer lines are replacing electricity with heat exchange oil heated by a waste energy from a central incinerator, backed up by electricity or gas. This can have processing complications especially if a fire in the oxidation occurs.