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Innovation in the man-made fibres industry: corporate strategy and national institutions

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1. Introduction

This paper is about success and failure in innovation. It is built around the experiences of three companies, all operating in the same industry, two of which can be described as innovation successes and the third as an innovation failure. The aim of the paper is to shed light on two questions. First, how do companies manage the innovation process, and why do some companies do it better than others? Second, how do national institutions – in particular, the role of financial markets - affect the way companies handle innovation?

The three companies are Courtaulds in Britain, Toray in Japan and Lenzing in Austria. All three were early leaders in the man-made fibres industry, although the first two later diversified in other directions. Courtaulds, once one of Britain's largest industrial groups, no longer exists as an independent company; it was taken over and broken up at the end of the 1990s. Toray is a major Japanese chemical company, with a substantial stake in fibres and textiles but also engaged in composite materials, pharmaceuticals and other businesses. Lenzing is a world leader in cellulosic fibres, with factories in the US, China and Indonesia as well as in Austria and the UK. Cellulosic fibres, of which rayon is the most important, use woodpulp as the starting material, whereas synthetic fibres such as nylon and polyester are derived from oil (Table 1).

Table 1 Principal man-made fibres

Cellulosic fibres (based on woodpulp)

Rayon (viscose), acetate, modal, lyocell (*Tencel)*

Synthetic fibres (based on oil)

Polyester, acrylic, nylon, polypropylene
Elastane/Spandex (*Lycra*)
Aramid (*Kevlar, Twaron*)

This paper focuses, not on the overall performance of the three companies, but on two episodes which are directly relevant to the management of innovation and which also highlight differences in the way the companies were run. One of these episodes is about carbon fibre; the other is about a cellulosic fibre, lyocell, better known under the brand name Tencel.

Carbon fibre is a high-strength material which was developed in the 1950s and 1960s and is now widely used in aircraft, sporting goods and a range of industrial products. Courtaulds was not involved in the early research, but once the scientific breakthroughs had been made it was quick to see the potential of the new material. In the mid-1970s it was the largest European producer and looked set to win a substantial share of the world market. Yet twenty years later it pulled out of carbon fibre production. It was Toray and other Japanese companies which profited from the subsequent growth of the industry.

Lyocell, or Tencel, is made from woodpulp, like rayon, but it has superior qualities in some applications and a more efficient manufacturing process. It was developed by Courtaulds in the 1980s and launched in 1992; at that time, and for some years afterwards, it was seen by investors as one of the company's most valuable assets. Yet Tencel did not produce profits as quickly as the company had hoped, and the failure of the new fibre to meet investor expectations was one of the factors that made Courtaulds vulnerable to takeover. The Tencel business was later acquired by Lenzing, which has done well with it; a new Tencel plant is now under construction in Austria.

Why did Toray and Lenzing succeed where Courtaulds failed? Was the outcome due to bad management on the part of the British company, or was the UK a less favourable environment than Japan or Austria for the kind of new product development in which the three companies were engaged?

The paper looks first at the evolution of the man-made fibres industry, noting the strategic dilemmas which the leading producers faced after the post-war boom came to an end in the mid-1970s. Section 3 briefly summarises the history of the three companies. This is followed in Sections 4 and 5 by an account of the carbon fibre and Tencel stories. The concluding section considers what lessons can be learned from these events about the management of innovation and about the link between the national environment and the innovation process.

2. The man-made fibres industry

The man-made fibres industry was born at the end of the 19^{th} century when a French entrepreneur found a way of converting cellulose, extracted from woodpulp, into artificial silk; this fibre was later given the more attractive name of rayon. The best of three competing processes for making artificial silk was the viscose process, invented in Europe and adopted later in the US and Japan. Rayon (or viscose – the two terms can be used interchangeably) was initially produced in filament form and processed in the same way as silk. The 1920s saw the introduction of rayon staple, which could be used as a substitute for cotton and opened up a much bigger market. Another cellulosic fibre introduced in the inter-war years was acetate yarn, which was superior to rayon in some applications and used in finer fabrics.

Nylon, the first of the synthetic fibres, was invented by DuPont in 1935. Only limited quantities were sold before the war, but it was a more versatile fibre than rayon – its first big market was in women's stockings – and it set the industry in a new direction. Other synthetic fibres, of which the most important were polyester and acrylic, were developed during and after the war.

As the advantages of the synthetics over cotton and wool, especially their easy-care properties, became more widely appreciated, demand for nylon, polyester and acrylic rose rapidly in the early post-war decades. Consumption of rayon continued to increase during this period but at a much slower rate (Table 2). Rayon has some cotton-like properties, notably absorbency, that the synthetics cannot match – it is often used in blends with polyester - but rayon fabrics are vulnerable to shrinkage and tend to fade when exposed to sunlight.

Table 2 World production of cotton and man-made fibres 1960-2010 (000 tonnes)

	Cotton	Man-made fibres	
		Synthetic	Cellulosic
1960	10113	702	2656
1980	13844	10635	3557
2000	18901	30288	2795
2011	26700	49765	4411

Source: CIRFS

The post-war boom came to an end in the mid-1970s. The rate of substitution of man-made for natural fibres was slowing down, and there was a swing back to cotton. At the same time the textile industry, the main outlet for fibres, was shifting to low-wage countries, principally in Asia. These problems were compounded by the recession in the world economy that followed the increase in oil prices in 1973-74. The result was a crisis of over-capacity in man-made fibres, especially severe in Europe, which prompted several companies to reduce their stake in the industry. In the 1980s several of the textile exporting countries, notably South Korea and Taiwan and later China on a much bigger scale, began to invest in their own fibre plants. Today more than three quarters of the world's fibre-making capacity is located in Asia, with China by far the largest producer (Table 3).

Table 3 Production of man-made fibres by region (tonnes)

	1977	2007
North America	3.7m (27%)	4.2m (9%)
West Europe	3.3m (25%)	4.8m (10%)
East Europe	2.2m (16%)	0.8m (2%)
Asia	3.2m (24%)	35.7m (75%)
Other	1.0m (8%)	2.0m (4%)
Total	13.3m	47.5m

Source: AFMA

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The man-made fibres industry in high-wage countries did not disappear, since there were some end-uses, principally outside clothing, which were less exposed to Asian competition. Manufacturers had to decide whether, by focusing on these markets, or by developing unique technology which Asian producers could not match, or by investing directly in the Asian countries where demand for fibres was growing, they could maintain a profitable fibres business. The alternative was to pull out, in which case they had to decide how and when to do so, and what non-fibre businesses to invest in. Several companies, such as ICI in the UK and Hoechst in Germany, withdrew from fibres during the 1980s and 1990s in order to concentrate on higher growth businesses. (A list of the leading producers in the 1970s is in Appendix 1). Courtaulds, Toray and Lenzing all stayed in the fibres business, with results that are summarised in the next section.

3. The three companies

Courtaulds

Founded in 1816, Courtaulds became one of the country's leading silk weavers, but by the end of the century its main product – mourning crepe – was in decline and new sources of growth were needed. In 1904 it acquired the patents for the viscose process. A factory was built in Coventry, and over the next few years Courtaulds established itself as the world's leading rayon producer. It was the first European company to start rayon production in the US; its American subsidiary accounted for a large share of its profits in the inter-war years.[1]

Following the invention of nylon, Courtaulds was eager to get into synthetics, and in 1940 it formed a joint nylon venture with ICI. (ICI had a patent-sharing agreement with DuPont and thus had access to the American company's nylon technology.) However, it was kept out of polyester by ICI, which was the principal patent holder[2], and although Courtaulds launched its own acrylic fibre, Courtelle, in 1959, it was still heavily dependent on slow-growing cellulosic fibres. Partly for that

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[1] Coleman, D.C., Courtaulds, *An economic and social history,* Vol I: *The nineteenth century – silk and crape,* Oxford 1969; Vol II *Rayon,* Oxford 1969; Vol III *Crisis and change 1940-1965,* Oxford 1980.

[2] Polyester fibre was invented by a British textile company, Calico Printers Association, but the patents were acquired by ICI, which had the technical and financial resources to exploit the new fibre.

reason, it diversified into other industries, principally paints and packaging. It also had a small textile business, derived from its earlier vocation as a silk weaver.

The diversification drive was stepped up in the mid-1960s, following an abortive attempt by ICI to take over Courtaulds.[3] The new management which took control of the company after the bid adopted a policy of forward integration, investing on a large scale in textiles and clothing in order to secure captive outlets for its fibres. The company also made further acquisitions outside fibres, principally in paints. A new business that was started in the 1960s, based on licensed technology, was carbon fibre, which is described more fully in the next section; carbon fibre later formed part of a new division, Courtaulds Advanced Materials.

The investment in textiles and clothing proved to be a serious mistake and in the mid-1970s Courtaulds was in financial trouble. Many of its textile mills and clothing factories could not compete with imports from low-wage countries; cutbacks in capacity were unavoidable. In fibres Courtaulds had been successful with Courtelle but still had a big commitment to cellulosics, the outlook for which looked unpromising. Of its various diversifications only paints had done well.

What followed in the 1980s was an attempt to reposition the company, aimed at businesses in which Courtaulds had, or could reasonably hope to create, a competitive advantage. Textiles and clothing were demerged into a separate company, Courtaulds Textiles; several downstream chemical businesses, principally in coatings and advanced materials, were acquired; and a woodpulp mill in South Africa which had been the principal supplier to Courtaulds' rayon factories, was sold. Fibres might have been divested during this period, but Courtelle was profitable, and the company had developed a new cellulosic fibre, based on the solvent spinning process (see below), which appeared to have excellent prospects. In 1990 the company decided to manufacture the new fibre, branded as Tencel, in the US; the factory came on stream in 1992.

By the mid-1990s Courtaulds had two main businesses, paints and fibres, of roughly equal size (Table 4), and at this point the company's financial position began to deteriorate. Profits from the older fibres had collapsed, while sales of Tencel, after a promising start, were slowing down. Several of the acquired businesses were performing poorly. The best part of the company was the paints division, and it attracted the attention of international paints companies which were seeking to enlarge their stake in this industry. In 1998 Akzo Nobel, the Dutch company, launched a successful takeover bid for Courtaulds. Its only interest was in paints; the fibres business, including Tencel, was later sold to CVC, a private equity firm.

Table 4 Courtaulds in 1997/98

	Sales	Operating profit
Coatings and sealants	49%	54%
Fibres and chemicals	39%	32%
Polymer products	12%	14%

Source: Courtaulds Annual Report 1997-98

Toray

Toray, then known as Toyo Rayon, was set up in 1926 by Mitsui, the trading company, to make rayon. Mitsui had been the sales agent in Japan for Courtaulds' rayon, and it tried to interest the British company in a joint manufacturing venture, but Courtaulds, focused on Europe and the US, had declined the invitation.[4] Most of the equipment and knowhow for the new factory came from Europe, but the Japanese rayon industry expanded rapidly in the inter-war years and by 1939 Toray and the other leading producers had caught up with their Western counterparts in scale and technology.

The invention of nylon prompted Toray to initiate research into synthetic fibres and it developed its own version of nylon, using a different process from DuPont, during the Second World War. Its

[3] ICI, which made polyester and nylon (through the joint venture with Courtaulds), argued when it announced the bid in 1961 that the combination of the two companies would greatly strengthen the British man-made fibres industry. The directors of Courtaulds argued that the company would do better on its own, and a majority of shareholders agreed with them..

[4] Toray Industries Inc, The history of Toray 1926-1996, 1999, p 19

polymerising and spinning technologies did not infringe DuPont's patents, but Toray decided after the war that access to DuPont's knowhow was necessary for a full assault on the nylon market; it negotiated a licence agreement in 1951. Four years later it secured a licence for polyester fibre from ICI, and after launching its own acrylic fibre it became one of the world's leading producers of all three high-volume fibres. Rayon production was cut back during the 1960s and finally terminated in 1975.

Some diversification took place in the 1950s and 1960s, but, in contrast to Courtaulds, it was achieved through in-house research rather than acquisitions. Toray used the knowhow it had developed in nylon and polyester to move into plastics and films. Polyester film was used as the base material for audio and video tape, linking Toray to Japan's powerful electronics industry. Another non-textile business, carbon fibre, which was to become an important source of profit, was started in the late 1960s.

Like other fibre producers Toray was hard hit by the downturn in demand that followed the oil crisis of 1973/74. The Japanese textile industry was in decline, and the scope for fibre exports was limited by the rise in production from Taiwan and South Korea. Toray's response was two-fold: to strengthen its position in fibres and textiles by moving part of its production to neighbouring Asian countries, while focusing its Japanese factories on high-end, technically sophisticated products; and to diversify.

There was never any question of withdrawing from fibres. It was a seen as a foundation business on which other businesses could be built, and it remained a major focus for Toray's research and development. The company's scientists looked for ways of adding functional properties to its fibres both for apparel and for industrial uses. A notable success was a silk-like version of polyester called Sillook, a lightweight material that could replace silk, not just in stockings as nylon had done, but in a wide range of apparel. First marketed in the mid-1960s, it became a profitable part of Toray's polyester division and led in the 1980s to a much improved version known as Shingosen which was hugely successful in the West as well as in Japan. Toray also launched a polyester-based suede material known as Ecsaine, aimed at the fashion industry.

Outside fibres, the existing plastics and films division was expanded. Nylon resin, for example, was used to make car radiators and other vehicle components, giving Toray a stake in Japan's fast-growing motor industry; nylon was also used later for automotive air bags. By the end of the 1980s about 50 per cent of Toray's sales came from fibres and textiles and another 23 per cent from plastics. Of the newer businesses, the most promising was carbon fibre.

After the bursting of Japan's bubble economy in 1991 and the subsequent appreciation of the yen, Toray made strenuous efforts to keep its fibres and textiles business competitive by rationalising its production in Japan and reorganising its network of overseas plants; the aim was to ensure that the label "Made in Toray" was a guarantee of quality, irrespective of the location of the factory. By this time China had become by far the world's largest producer of textiles and clothing, and in 1995 Toray extended its international network by building a polyester complex in Nantong.

Since then Toray's portfolio of businesses has evolved incrementally, without drastic changes of direction and without major acquisitions or divestments. The company has continued to invest in its foundation businesses – fibres and textiles, and plastics and chemicals – while looking for growth from what it calls its "strategically expanding businesses" – IT-related products (which include materials for flat panel displays) and carbon fibre composite materials. A third category, classified as "intensively developing and expanding businesses", consists of environment and engineering (including water treatment) and life science (Table 5).

Table 5 Toray in 2011/12

	Net sales (% of total)	Operating income (% of total)
Fibres and textiles	40.5	36.0
Plastics and chemicals	25.3	21.7
IT-related products	15.4	27.4
Carbon fibre composite materials	4.4	6.1
Environment and engineering	10.8	3.9
Life science	3.6	4.8

Source: Toray Annual Report 2011/12

Lenzing

The rayon factory in the town of Lenzing, situated in Upper Austria between Salzburg and Linz, was built in 1938 as part of the Nazi authorities' self-sufficiency programme; a number of plants were built in Southern Germany and Austria in order to replace cotton imports. The rayon factory was adjacent to an existing pulp mill, which became the main source of woodpulp; the mill was bought by Lenzing in 1969. The integration of pulp and rayon production gave Lenzing a cost advantage over rayon producers such as Courtaulds which obtained their wood pulp from distant suppliers.[5]

After the war the company was controlled by two partially state-owned banks, Landerbank and Creditanstalt. Subsequent mergers in the Austrian banking industry led to the creation of Bank Austria, which became the principal shareholder. Lenzing was listed on the Vienna Stock Exchange in 1985 but only about 10 per cent of the shares were offered to outside investors. Lenzing was expected to make profits and to pay dividends but it was not a shareholder-driven company. As the principal employer in its region, it had a social responsibility which influenced its strategic decisions, not least its determination to make the best possible use of the site.

A drawback of the site was the lack of water and Lenzing had to invest in costly techniques to reduce its water consumption while also meeting the environmental rules laid down by the regional government. The result was a cleaner manufacturing process, giving the company the confidence to continue improving the viscose process at a time when other producers were cutting back. Lenzing also developed speciality cellulosic fibres, of which the most important was modal; launched in 1964, this was a "high wet modulus" fibre, stronger than rayon and suitable for high-tenacity applications.

Lenzing took a cautious approach to synthetic fibres. It made a brief foray into acrylics and later into polyester in partnership with Hoechst, but was never a major producer[6]. Because of its limited involvement in synthetics, Lenzing was less affected than most other European fibre producers by the over-capacity crisis of the mid-1970s. At the end of that decade it made what turned out to be an important decision to participate in an Indonesian viscose plant with the Indian Ashok Birla group. The Indians had asked for technical assistance and in exchange Lenzing secured a minority interest in the new company. This plant, which started production in 1982, gave the Austrian company a foothold in a region where demand for man-made fibres was growing fast, and paved the way for subsequent investments in Asia; Lenzing later acquired majority control of the Indonesian company.

Like Courtaulds, Lenzing was aware of possible alternatives to the viscose process and it initiated research into solvent spinning during the 1980s. A pilot plant was built in 1990 and five years later Lenzing decided to manufacture its own lyocell fibre, a direct competitor to Tencel; production began in 1997. In 2004 Lenzing bought the ex-Courtaulds Tencel business from CVC. This added the two Tencel plants which Courtaulds had built, in the UK and the US, to Lenzing's existing plant in Austria. All three factories were subsequently expanded, and in 2010 Lenzing announced plans to build a new Tencel plant in Austria.

The Tencel takeover was one of a series of moves which gave the Austrian company a more international dimension. The Indonesian plant was enlarged and in 2005 the decision was taken to build a viscose plant at Nanjing, China; another Asian viscose plant, in India, is expected to come on stream in 2013. Lenzing is now one of the two leading producers of cellulosic fibres, the other being the Aditya Birla group in India. Nearly 60 per cent of its sales come from Asia, but the heart of the company remains the original site in Lenzing; some 3,000 out of the company's total labour force of 6,600 are employed there.

Although Lenzing has diversified on a small scale outside fibres, principally in plastics, its strategy since the war has been based on the belief that, with continuous investment in new technology and new product development, cellulosic fibres will remain a good business to be in.

[5] In 2010, to supplement its woodpulp supplies, Lenzing acquired control of a Czech pulp mill. It plans it source two thirds of its pulp needs from internal sources.

[6] Lenzing produces speciality grades of acrylic fibre at an associated company in Kelheim, Bavaria; the Kelheim at plant also produces polyacrylonitrile (PAN) precursor for carbon fibre.

This consistency has been reinforced by the company's ownership structure. In 2000 Bank Austria sold its shares to an Austrian foundation, the B & C Private Foundation, whose mission was to act as a long-term core investor in Lenzing, with a commitment to maintain the company's role in the Austrian economy. In 2011, as part of a capital reconstruction which involved the issue of new shares, B & C reduced its share of the voting shares to 68 per cent and the free float was increased to about 33 per cent.[7] Part of the motivation was to make Lenzing shares more accessible to international investors.

Table 6 Lenzing sales in 2011 (millions of euros)

Fibres	2,140 (90.0%)
Plastics	143 (8%)
Engineering	38 (1.9%
Other	- (0.1%)

Source: Lenzing Annual Report 2011

4. Carbon fibre: Courtaulds versus Toray

Background

The technique of carbonising an organic material – removing most of the non-carbon atoms to produce filaments - has been known since the nineteenth century. Edison and Swan used it to make lamp filaments before tungsten wire was found to be a more efficient material. But the idea of blending these filaments with a synthetic resin to produce a composite did not come to the fore until after the Second World War. Some early work took place in the US, stimulated by the requirement of the Department of Defence for heat-resistant materials for use in rockets. Union Carbide used rayon as the precursor for a carbon fibre composite that was used in rocket nozzles and re-entry heat shields.[8]

Research in the same field was taking place in Japan and an important breakthrough was made by a Japanese scientist, Dr Akio Shindo, working in the government's Industrial Research Institute in Osaka. He showed that using polyacrylonitrile (PAN), the polymer out of which acrylic fibre is made, as the precursor produced a stronger material than rayon. His patent was filed in 1959 and the technology was licensed first to Tokai Electrode and Nippon Carbon, and later to Toray, which was to become Japan's leading carbon fibre manufacturer.

The next big advance was made in the UK. British scientists in the Royal Aircraft Establishment at Farnborough were conducting research into light-weight structural materials for aircraft. They were aware of Dr Shindo's work, and they found that by stretching the PAN polymer in the initial oxidisation phase and by improving the heat treatment process they could produce a much stronger and stiffer material than the Shindo process; the RAE invention was patented in 1963. The RAE team subsequently cooperated with another government laboratory, the Atomic Energy Research Establishment at Harwell, which had experience in high-temperature graphite technology, in scaling up the manufacturing process.

In 1967 the National Research Development Corporation, the government agency responsible for commercialising publicly-financed research, licensed the RAE's technology to three British companies: Rolls-Royce, which had been investigating the use of carbon fibre in its aero engines; Morgan Crucible, which had expertise in high-temperature technology and an understanding of graphite structures; and Courtaulds, which made the acrylic precursor.[9] Courtaulds had worked closely with the RAE researchers, who had found that the optimum chemistry for the PAN precursor for carbon fibre was almost the same as for Courtelle, Courtaulds' textile fibre.

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[7] Just over 5 per cent of the voting shares are held by Oberbank, a regional bank.

[8] Graham Spinardi, 'Industrial exploitation of carbon fibre in the UK, USA and Japan', *Technology Analysis and Strategic Management*, Vol 14, No 2, 2002

[9] The NRDC also licensed the RAE process to several Japanese companies; the Japanese were not seen at that time as likely to become significant competitors in carbon fibre.

All three licensees set up small production plants for carbon fibre. Courtaulds (which filed some 51 patents of its own) made Special Acrylic Fibre (SAF) in Coventry, using precursor brought by truck from its acrylic fibre plant in Grimsby. This produced a narrow ribbon-like tow containing 10,000-12,000 filaments, used in applications where exceptionally high strength and low weight were required; this small tow fibre was branded as Grafil. A heavier or large tow material, known as Textile Tow Precursor (TTP) and containing more than 24,000 filaments, was made at Grimsby alongside the acrylic fibre plant; it was aimed at less demanding industrial applications such as brake discs for aircraft wheels.

The carbon fibre production chain

1. The starting point is a precursor material, most commonly polyacrylonitrile (PAN), though rayon and pitch can also be used

2. The precursor is subjected to two processes, oxidisation and carbonisation, to produce bundles of fibres which are held together by a small amount of resin. These bundles can be produced in a range of thicknesses, from fine bundles made up of a few thousand filaments (suitable for components that need very precise formulation), to large-tow bundles made up of many thousands of filaments, used in less demanding applications.

3. The carbon fibre is blended with a synthetic resin (most commonly epoxy resin) to produce intermediate products - usually pre-impregnated tapes (prepregs) or sheets. The quality of these intermediate materials is crucially dependent on the quality of the precursor.

4. The intermediate products are fabricated into composite parts to meet the customer's specification.

Notes

a) In the early years carbon fibre producers were responsible for steps 1 and 2, and were only involved in step 3 to the extent that it was necessary to demonstrate to prepreg and composite manufacturers how the material was to be used. Subsequently the trend was towards greater integration, with most carbon fibre producers vertically integrated from precursor through to the manufacture of prepregs and other intermediate materials.
b) Carbon fibre can be produced as small tow fibre (ranging from 1,000 to 24,000 filaments in each bundle) or large tow (above 24,000 filaments). The former is used where exceptionally high strength and stiffness are required.

When the RAE's work was made public there was considerable enthusiasm in Britain, not just from the aircraft industry but from politicians and others who believed that the UK had a lead in a promising new technology. According to a report from the House of Commons Select Committee on Science and Technology, published in 1969, the RAE's research created a huge opportunity for Britain. 'It is of the utmost national importance that a large-scale plant for producing carbon fibre is built in this country without delay.'[10] The sense of urgency reflected the widely held view that too many British inventions – penicillin was often cited - had been exploited by foreign rather than British companies; this must not be allowed to happen in carbon fibre.

Because of its lightness and strength, the initial demand for carbon fibre was expected to come from the aircraft industry. British Aircraft Corporation, the principal UK aircraft manufacturer, planned to use it in the fuselage and wing structures of a new airliner. Rolls-Royce chose to use carbon fibre in the forward compressor blades of its first turbofan engine, the RB211. This was an innovative light-weight engine, aimed at enabling Rolls-Royce to steal a march on its two American rivals, General Electric and Pratt & Whitney.

[10] House of Commons Select Committee on Science and Technology, *Carbon Fibres Report*, HC 157, HMSO London 1969.

When several US airlines chose the RB211 to power Lockheed's new wide-bodied airliner, the Tristar, this was acclaimed as a vote of confidence in the new engine and in carbon fibre; it attracted worldwide attention. Thus it came as a shock to Britain's fledgling carbon fibre industry when, in the summer of 1969, Rolls-Royce announced that the compressor blades on the RB211 had disintegrated when subjected to a bird impact test. The engine had to be redesigned using forged titanium instead of carbon fibre. The subsequent delay in fulfilling the Lockheed contract led to a financial crisis which forced the government to take Rolls-Royce into public ownership.

This episode dispelled some of the optimism expressed in the House of Commons report.[11] However, the US aerospace industry, far larger than its British counterpart, was already using carbon fibre, based on rayon precursor, and despite what had happened at Rolls-Royce several American companies believed that the RAE's process was superior to other processes then in use. Of the three NRDC licensees, Courtaulds was the most eager to build up its carbon fibre business and it received several approaches from American firms. As one manager recalled later, "The pace of development was hectic and invigorating, with major US aerospace companies such as Boeing routinely flying over with suitcases full of dollars and returning with them full of Grafil carbon fibre". Because of the focus on aerospace and the US, not much attention was paid to Japan, either as a market or as a potential competitor

Courtaulds and the US market

To tap into the US market Courtaulds signed a technical agreement with Hercules, a chemical company that made composite materials for missile applications. Courtaulds made its carbon fibre know-how available to Hercules in exchange for a royalty, although the agreement did not cover the precursor; Courtaulds kept that technology to itself. Hercules built a carbon fibre plant at Salt Lake City, using precursor imported from the UK.[12]

The partnership began well, with the two companies cooperating not only on the manufacturing process but also on downstream product development. What soon became evident, however, was that Grafil had some disadvantages, especially in aerospace applications. Grafil was initially based on 5K and 10K filament tow bundles, whereas competing suppliers provided 3K, 6K and 12K bundles and the latter came to be accepted as standard in US aerospace. There were also impurities in the precursor which could be tolerated in less demanding applications but not in aerospace. Courtaulds' reluctance or inability to correct these problems led to a souring of the relationship with Hercules. In 1979 the American company terminated the partnership and switched to a Japanese precursor supplier, Sumitomo Corporation.

Meanwhile a new market for carbon fibre had emerged. In 1972 an American entrepreneur, Jim Flood, discovered that golf club shafts made of carbon fibre instead of steel could increase the length of an average golfer's drive by at least thirty yards. (Jim Flood has been described as the Thomas Edison of modern golf.) This was a market that Japanese carbon fibre producers – who had no domestic aerospace industry to serve - were quicker to exploit than their European and American counterparts. Japanese golfers, generally smaller and less powerful than Americans or Europeans, took to the new design with great enthusiasm. The use of carbon fibre was later extended to tennis rackets, ski poles and other sporting goods. The main centres for sporting goods production were Taiwan and South Korea, and producers in these countries became large buyers of carbon fibre from Japan.

Like Courtaulds, the Japanese carbon fibre firms had a background in acrylic fibre and several of them, including Toray, made their own precursor. One which did not in the early years was Mitsubishi Rayon, and this company turned to Courtaulds as a precursor supplier and as source of advice on carbon fibre technology. While Courtaulds provided technical support, the Japanese partner gave Courtaulds access to sales outlets in Japan and East Asia. Mitsubishi Rayon made its

[11] Rolls-Royce had built a small carbon fibre plant of its own which it tried to sell to ICI, but the offer was declined on the grounds that the development costs were likely to be very high and the market was uncertain.

[12] Morgan Crucible made a similar agreement with the Whittaker Corporation whose Narmco subsidiary was a supplier of high-performance resins and pre-impregnated fibre systems. Narmco was later acquired by Celanese Corporation, which became, along with Hercules and Union Carbide, one of the leading US carbon fibre producers. In 1985 Celanese sold its carbon fibre business to the German chemical company, BASF. .

own golf club shafts out of Grafil, and Courtaulds won a substantial share of the Asian sporting goods market.

This was a boost for Grafil, but, as Table 7 shows, the largest outlet for carbon fibre was the US. Following the breakdown of the relationship with Hercules, Courtaulds looked for other partners, and in 1983 set up a joint venture with Dexter Corporation, whose Hysol division specialised in aerospace film adhesives and resin formulation. The new company, Hysol Grafil, built a carbon fibre plant in Sacramento, California, and the hope was that the combination of an in-house source of precursor and Dexter's expertise in resins would pave the way for qualification into US aerospace and defence programmes. However, the partnership did not work well. The materials developed by the joint venture turned out to be no better than those of other suppliers. Moreover, Courtaulds' move downstream made it more difficult to sell Grafil to competing producers of intermediate materials. With Dexter apparently dissatisfied with the quality of the carbon fibre coming out of Sacramento, the two partners became disenchanted with each other. In 1987 Courtaulds acquired majority control of Hysol Grafil and subsequently bought out Dexter's minority share.

Table 7 Carbon fibre consumption in 1984 (tonnes)

	Europe	US	Japan	Total
Aerospace	330	1110	50	1490
Sports goods	200	400	500	1100
Industrial	180	300	350	830
Totals	710	1810	900	3420

Source: US Office of Technology Assessment, Washington 1988

Despite this disappointment, Courtaulds still saw carbon fibre as a potentially high-growth business. The company told its shareholders in 1986 that carbon fibre "will form part of a drive into composite materials, intended to give Courtaulds a firm foundation in the fibre reinforced materials field, which it is hoped will in the long term produce a major new business".[13] In the following year Courtaulds acquired a British company, Fothergill & Harvey, which was active in this field; it was put into a new division, Courtaulds Advanced Materials, alongside Hysol Grafil.[14] Courtaulds claimed that the new division's "unique combination of skills" would enable Courtaulds to increase its share of the market for fibre-reinforced materials. This market, the company said, was expanding at some 15 per cent per annum, and "offers the prospect of explosive growth as manufacturing techniques develop and drive down fabrication costs".[15]

It was certainly true that world carbon fibre consumption, after a sluggish start, was now growing at a spectacular rate (Table 8). Apart from sporting goods, an increasingly important outlet was civil aerospace, as companies such as Boeing and Airbus looked for ways of making their aircraft lighter and more fuel efficient. As volumes increased and the price came down, carbon fibre was also finding a market in engineering applications outside aerospace, although the motor industry, which had been seen at the start as a potentially large customer, was not yet buying carbon fibre on any scale because the price was too high.[16]

[13] Courtaulds Annual Report 1985/86.

[14] The value of Fothergill & Harvey to Courtaulds was reduced by the exclusion of a business, jointly owned with American Cyanamid, making lightweight materials for the aerospace industry. The US company had the right to acquire full control of this business in the event of a change of control of Fothergill, and it did so.

[15] Courtaulds Annual Report 1987/88

[16] The price of standard carbon fibre, which had been $330 per kilo in the early 1970s, fell to about $44 in the mid-1980s, and declined further to $26 in the mid-1990s.

Table 8 World carbon fibre demand 1980-1988 (tonnes)

	1980	1988
US	450	2650
Europe	130	900
Japan	270	950
Others	-	1000
Total	850	5500

Source: Financial Times April 24, 1989

Much of the US demand for precursor and for carbon fibre was met from the UK and Japan. In 1987 the US Department of Defense, concerned that the US was too dependent for supplies of a strategic material on non-American sources, ruled that henceforth at least 50 per cent of all carbon fibre used in government-financed programmes, and 50 per cent of the precursor, must be made in the US. This prompted a surge of investment in new capacity by American and non-American carbon fibre producers, including BASF, the German chemical group which had bought the Celanese carbon fibre operations in 1985. However, by the time the new plants came on stream, the Cold War was over and orders from the Defence Department dried up. Between 1987 and 1991 demand for carbon fibre from the US aerospace industry dropped by more than a third (Table 9). The result was a crisis of overcapacity and a plunge in prices, prompting several companies to withdraw from the industry.

Table 9 World carbon fibre consumption 1987 and 1981 (tonnes)

1987

	Aerospace	Sports	Industrial	Total
US	1500	320	450	2270
Europe	430	150	190	770
Japan	40	650	160	850
Others	40	630	120	790
Total	2020	1750	920	4690

1991

	Aerospace	Sports	Industrial	Total
US	1080	530	590	2200
Europe	645	325	290	1260
Japan	60	810	490	1360
Taiwan/Korea	-	1350	-	1350
Total	1785	3015	1370	6170

Source: industry estimates drawn from Celia Russell, International competition in the advanced materials sector: the case of carbon fibre, PhD thesis, Manchester University, 1996

The first casualty was Courtaulds which closed its Coventry plant in 1991 and sold the Sacramento factory to its Japanese partner Mitsubishi Rayon.[17] This was not directly due to the cutback in defence orders since Courtaulds had only a small share of that market. However, the general fall in carbon fibre prices, coming after a period of erratic financial performance, convinced the top management that further investment in carbon fibre could not be justified. By this time Courtaulds had scaled back its ambitions; it now saw itself primarily as a low-cost producer of mid-specification fibre for the leisure and industrial markets. It still hoped to develop its advanced materials business, but no longer linked to an in-house source of carbon fibre. After the Coventry closure Courtaulds continued to produce Textile Tow Precursor at Grimsby for sale to other carbon fibre producers and this helped to sustain the profitability of the Grimsby acrylic fibre plant.[18]

Several other carbon fibre companies also admitted defeat. BASF tried to sell its big plant at Rock Hill, South Carolina (originally built by Celanese) and later mothballed it in the hope that a buyer might appear. Hercules and Amoco (which had bought Union Carbide's carbon fibre business in 1986) would probably have withdrawn had not President Clinton introduced the Technology Reinvestment Project which provided funds for defence companies to adapt their facilities for civilian markets. Both companies took advantage of this arrangement and stayed in the market though not for long. In 1996 Hercules sold its carbon fibre business to Hexcel, a manufacturer of high-strength composite materials. Two years later Amoco was acquired by BP, the British oil company, which persisted with carbon fibre for several years before selling it to Cytec Industries in 2001.

The one group of producers which, far from pulling out, continued to invest in carbon fibre during the "détente recession" were the three leading Japanese firms, Toray, Toho Rayon and Mitsubishi Rayon.[19] Asahi Kasei was the only one of the original producers to withdraw.[20] These three companies were well placed to take advantage of the recovery in demand that began in the mid-1990s and they went on to dominate the industry (Table 10) In 1995 Japanese-owned plants, which by then included carbon fibre factories in Europe and the US as well as Japan, accounted for 62 per cent of world carbon fibre production. The European-owned share, which in 1988 had been 24 per cent, was down to 3.2 per cent.

Table 10 Leading carbon fibre producers in 1988, 1995 and 2008 (capacity in tonnes)

1988		**1995**		**2008**	
Toray	1500	**Toray**	3,300	**Toray**	17,600
Toho Rayon	1420	**Toho Rayon**	3,150	**Toho Tenax**	10,500
Hercules	1050	**Hercules**	1,750	**Mitsubishi Rayon**	7,400
Courtaulds	750	**Mitsubishi Rayon**	1,050	**Formosa Plastics**	3,900

[17] Mitsubishi replaced Courtaulds' acrylic precursor, supplied from the UK, with precursor made in Japan. The Japanese company declined to buy the Coventry plant, partly because it was a high-cost inner-city site. Some of the equipment at Coventry was sold to Zoltek, a recent entrant to the carbon fibre industry, for installation at St Louis, Missouri; Zoltek became a major supplier of large-tow carbon fibre

[18] The TTP operation at Grimsby was subsequently taken over by a Chinese-owned company, Blue Star Fibres, which continues to manufacture both precursor and large-tow carbon fibre on that site. After the carbon fibre closure Courtaulds maintained an advanced materials business – later renamed Aerospace Composites – but most of it was sold before the Akzo Nobel takeover in 1998. Fothergill & Harvey proved to be a disappointing acquisition; its only strong business was in PTFE coated fabrics (Tygaflor), which was sold in 1996.

[19] Toho Rayon, renamed Toho Tenax, became part of the Teijin group in 2000. Teijin is the second largest Japanese synthetic fibre producer after Toray.

[20] Asahi Kasei had started carbon fibre production with Nippon Carbon, but the partnership was dissolved in 1986 and Asahi Kasei continued on its own. By the early 1990s, having made little headway in aerospace, it depended mainly on sporting goods, where price competition was intense. It pulled out of carbon fibre in 1994.

BASF	450	**Amoco**	950	**Hexcel**	4,200
Amoco	450			**Cytec**	1,900

Note: these figures relate to small tow carbon fibre. The leading producers of large tow fibre in 2008 were Zoltek in the US (11,000 tonnes) and SGL in Germany (5,000 tonnes).)

Source: industry estimates

The strongest of the Japanese companies was Toray, which in the twenty years following the "détente recession" consolidated its lead over the rest of the industry. Yet this was a company which in the early 1970s had seemed no better equipped to compete in carbon fibre than Courtaulds in the UK. Both companies had benefited from government-financed research; in technology and scale of production they were roughly on a par; and both seemed well set to win a share of the US market. Why did the Japanese company come out on top?

Toray

Like Courtaulds, Toray began its research into carbon fibre in the 1960s. It had been making acrylic fibre for the textile industry since 1964 and when Dr Shindo showed that polyacrylonitrile was a suitable precursor, Toray saw that carbon fibre presented an attractive business opportunity. Together with two other acrylic fibre producers, Toho Rayon and Asahi Kasei (Mitsubishi Rayon came in later), Toray obtained the rights to use Dr Shindo's process and set up a pilot plant at Shiga in 1971; its Torayca T300 fibre was launched later that year.

At that time the textile industry which was the principal outlet for acrylic fibre was depressed, and carbon fibre allowed the Japanese producers to exploit their acrylic capacity in a more profitable and faster-growing industry. As a senior executive in Toho Rayon, Toray's main competitor, wrote later, "Japan's acrylic industry was struggling, having started quite far behind the West. Even within the Japanese acrylic industry, Toray and Toho Rayon were the latest entrants of all, and suffered accordingly. The intensely hungry spirit that built up during that time is what guided these two companies to global supremacy in the PAN-based carbon fibre business."[21]

Toray's work on carbon fibre attracted the interest of American producers, and in 1970 it concluded a technology agreement with Union Carbide, which had been the leading producer of rayon-based carbon fibre. The American company gained access to Toray's precursor technology in exchange for its carbonising technology, and Toray began to export its Torayca fibre to the US through Union Carbide. However, the biggest spur to Toray's carbon fibre business in the early years came from sporting goods. Its first carbon fibre product was a fishing rod, and when golf clubs with carbon fibre shafts were introduced Toray devoted a large part of its development effort to this business, providing extensive sales and engineering support and helping to enlarge the market.[22] A new plant was built at Ehime in 1973 with a capacity of five tonnes per month, followed by the installation of prepreg and fabric facilities. The Torayca Sales and Marketing Department was established in 1974.

In the second half of the 1970s, following the oil price increase of 1973/74, civil airliner makers such as Boeing and Airbus sought to make their aircraft lighter and more fuel-efficient through the use of carbon fibre, and this opened up a new market for Toray. Its partner, Union Carbide, abandoned its rayon precursor in favour of Toray's product, and the Torayca T300 became the best-selling fibre in the US. In 1975 Toray's carbon fibre was used in the secondary structure of the Boeing 737, marking the start of a long and profitable relationship between the two companies.

The licensing deal with Union Carbide expired in 1987, and although Toray maintained a technology agreement with Amoco, which had taken over Union Carbide's carbon fibre facilities, it was now free to sell direct to customers in the US. In 1990 a new fracture-toughened prepreg became the sole carbon fibre material approved by Boeing as a primary structural material for use in the Boeing 777.

Meanwhile Toray was also winning business from Airbus in Europe. The French government was eager to establish a domestic source of carbon fibre, and in 1982 a new company was set up,

[21] Keizo Kanegae, 'Study of the historical development of PAN-based carbon fibres', a study made available to the author by Toho Rayon.

[22] Toray Industries Inc, The history of Toray 1926-1996, published by Toray in 1999, p164.

Societe des Fibres de Carbone SA (Soficar), in which Toray held a 35 per cent interest and Elf Aquitaine, the state-owned oil company, the balance. In 1987 Toray's T300 carbon fibre was approved as a primary material for use in the Airbus A320.[23] .

At the end of the 1980s, with production in Japan and in France at full capacity, profits from the Torayca business were at an all-time high. Then came the "détente recession" and sales of Torayca fell sharply, putting the division into loss in 1993 and 1994. But Toray never wavered in its commitment to carbon fibre. In the US, where it had previously relied on partners and on exports from Japan, Toray decided now to invest directly. To strengthen its links with Boeing, it built a plant in Tacoma, Washington, to make its new high-strength prepreg, and a carbon fibre factory in Decatur, Alabama.

Patience, in Toray's case, was rewarded. Since the mid-1990s world consumption of carbon fibre has increased at a rate of some 15 per cent a year. Civil aerospace remains a key market, especially for the most technically advanced carbon fibre grades. The newest aircraft from Boeing and Airbus, the Boeing 787 and the Airbus A350, have primary structures that contain as much at 50 per cent carbon fibre by weight.[24] However, thanks to the continuing fall in prices for standard carbon fibre, industrial applications now provide the bulk of demand (Table 11). An important new source of demand has come from wind turbines, and the motor industry is also now a significant consumer. In 2011 Toray formed a joint venture with Daimler for the manufacture and marketing and of fibre composite parts.

Table 11 World carbon fibre demand (tonnes)

	2009	2015 (forecast)
Aerospace	5,800 (17%)	13,090 (15%)
Consumer	6,420 (19%)	9,410 (11%)
Energy and industrial	21,210 (63%)	66,760 (75%)
Total	33,430	89,260

Source: Chris Red and Tony Roberts, Composites World, March 2011

To keep pace with demand Toray is building a fourth production centre in Korea, to complement its existing carbon fibre sites in Japan, France and the US, and a precursor plant in France, which will replace imports from Japan. With these and other investments that are now under way, Toray's worldwide carbon fibre capacity will increase from 17,900 tonnes of capacity in 2012 to 27,100 tons by 2015.

Assessment

Why did Courtaulds fail in carbon fibre despite its early lead? Three important contributory factors were: quality shortcomings in the acrylic precursor; an inability to make full use of partnerships with American and Japanese companies; and the failure to recognise that carbon fibre, because of the protracted market development that would be necessary, needed to be managed in a different way from the company's mainstream fibres.

The wet spinning process which was used for the production of Courtelle had some advantages in carbon fibre – it allowed oxidation to take place more gradually and at lower temperatures than other fibre-making processes – but because it was designed for high-volume textile fibre production it was less suitable for the precise formulations that were needed in aerospace. The precursor suffered from a lack of consistency and processability, often leading to broken filaments which affected the appearance of the final product. The shortcomings of the precursor positioned

[23] Toray's principal Japanese competitor, Toho Rayon, also entered the European market through a joint venture with Akzo in Holland, signed in 1983; a jointly owned plant was built at Oberbruch in Germany. Toho Rayon acquired majority control of this business in 1992.
[24] In 2010 Toray signed a long-term agreement with EADS, the parent company of Airbus, for the supply of carbon fibre prepregs over a fifteen-year period to 2015.

Grafil fibres outside the key aerospace opportunities and restricted market penetration to less critical end uses.

Courtaulds might have solved the precursor problem if it had been willing to work more closely with its two partners, Hercules and Mitsubishi Rayon, but it was reluctant to share its carbon fibre technology; both these companies later developed their own precursor. The most enduring partnership was with Mitsubishi Rayon – it lasted from the early 1970s until 1991 when the Japanese company acquired the Grafil operation in the US – and it helped Courtaulds build up a sizeable business in Asia. There was extensive technical collaboration between the two companies and some discussion of manufacturing joint ventures but nothing substantive resulted.

Another mistake was to have established carbon fibre (after it was moved out of the Research Division) as a unit within Courtaulds Fibres alongside the much larger acrylic and viscose fibre businesses. The managers who controlled the programme, coming mainly from a commodity fibres background, viewed Grafil as an interesting speciality but still applied the same targets for growth and financial returns they would for a textile fibres business. The investments required and the losses sustained as the market proved slow to develop were a focus of concern and there was significant frustration that the potential offered initially was taking so much longer to mature than anticipated.

From the mid-1970s onwards carbon fibre had a higher priority within Toray than within Courtaulds. The establishment of Toray's Advanced Composite Materials Division in 1983 gave the managers of the carbon fibres business a status and autonomy that their counterparts in Courtaulds never achieved. Yet the key to Toray's success was meticulous control of quality, in the precursor and the carbon fibre, coupled with close attention to customer requirements.

These are all managerial factors and they go a long way towards explaining why Toray succeeded in carbon fibre and Courtaulds did not. It is worth noting, however, that Courtaulds was not the only Western company to give up on carbon fibre during the 1990s. Two other European companies, BASF and Akzo, also pulled out. Akzo had formed a joint venture with Toho Rayon in Germany, and had also invested in the US, but the collapse in demand after 1990 prompted its withdrawal from both operations. Several other major European corporations, including BP and ICI, have had little success in advanced materials[25].

Asked in the late 1990s to explain Japan's success in carbon fibre, a senior Japanese executive pointed to several factors which helped the Japanese to get ahead.[26]. One was the Shindo patent, which got the industry started. Another was the golf club boom – "a divine wind" for the Japanese carbon fibre industry as the executive put it. The proximity of the main sports goods production centres in Korea and Taiwan was also helpful. The executive noted that sporting goods provided an easier opening for the carbon fibre producers than aero engines. "Britain could have become the pioneer of industrialisation in PAN carbon fibre but failed. In retrospect, they should have avoided applying PAN CF, an innovative material, to such a difficult material as aero engines, and they were discouraged when that experiment failed".

The same executive also suggested a cultural explanation. "The major western companies do not mind a bold attempt when starting a new business, and at the same time they pull out of the market swiftly if it does not do well. Carbon fibre requires a long time in developing technology and market. Its market is not huge and demand is not consistent. Therefore Western-style management might not be suitable for this product development……Mergers and acquisitions are not uncommon in Europe and the US. Japanese companies tend to be more cautious when it comes to starting and closing a new business".

Another observer has argued that part of the reason for the success of Toray and other Japanese companies was the absence of the shareholder pressure which, in the US and the UK, forces companies to withdraw from poorly performing businesses.[27]The author of this study notes

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[25] When ICI bought Beatrice Chemicals in the US in 1985, its main target was Beatrice's Fiberite subsidiary, a leading manuifacturer of composite materials, but the acquisition was disappointing and ICI subsequently withdrew from advanced materials. In 1990 BP bought Hitco, which made carbon fibre products, and in 1998 it increased its stake in advanced materials when it bought Amoco (which had earlier acquired Union Carbide's carbon fibre business), but all these businesses were later sold.

[26] Keizo Kanegae, 'Study of the historical development of PAN-based carbon fibres.

[27] Celia A. Russell, 'International competition in the advanced materials sector: the case of carbon fibre', Unpublished PhD thesis, Manchester University 1996.

that three of the four main Japanese carbon fibre producers in the 1980s – Toray, Toho Rayon and Mitsubishi Rayon – belonged to keiretsu groups. Members of keiretsus held shares in each other and these inter-company holdings were large enough to insulate them from pressure from outside shareholders; the stock market was not a significant influence on their decisions. Only Asahi Kasei did not belong to such a group and, as noted earlier, this company abandoned carbon fibre manufacture in 1994.

These wider issues are considered in the concluding section of the paper.

5. Lyocell (Tencel): Courtaulds versus Lenzing

Background

The man-made fibres industry up to the Second World War was based mainly on the viscose process, and the principal fibre was rayon. With the introduction of synthetic fibres – first nylon, then polyester and acrylic – the growth of rayon consumption slowed down. During the 1960s and the 1970s several companies, including DuPont in the US and Toray in Japan, withdrew from cellulosic fibres to concentrate wholly on synthetics. Yet rayon, as a cellulosic fibre, had some cotton-like properties – notably absorbency and softness to the skin – which the synthetics could not match. Although as a commodity fibre rayon was no match for polyester, it retained a market position, both in apparel and in non-woven applications such as wipes and hygienic products, that was large enough to generate adequate profits for efficient, low-cost producers.

A disadvantage of the viscose process – and this was one of the reasons why several companies abandoned it – was that it was highly polluting. It used several toxic chemicals, most of which had to be disposed of as effluent (see Appendix 2 for a brief description of the process). The search for a cleaner process, which began in the 1920s, was based on the idea that, instead of breaking up the cellulose extracted from woodpulp and regenerating it, cellulose might be dissolved directly using chemicals which would be easy to use and recover. The most promising solvent, first identified by two Swiss chemists in 1939, was an amine oxide, a non-toxic chemical, and this work was taken further after the war by Eastman Kodak in the US.

Eastman's scientists filed their first solvent-spinning patent in 1966 but the company decided not to commercialise the process. American Enka, the US affiliate of the Dutch company Akzo, acquired the patents and made further improvements, principally in the solvent composition and in spinning. However, the company ran into problems when it tried to produce fibre on a large scale and spinning quality was poor. The Dutch parent company discontinued the work on solvent spinning and in 1985 sold American Enka to the German chemical company, BASF. The patents that American Enka had filed were put together in a manual and offered for sale.

Courtaulds and Tencel

Courtaulds was aware of what American Enka had been doing and their researchers saw that the solvent spinning process, if it could be made to work, might have important advantages. In 1979 a research team was set up in Coventry under Pat White, who had earlier worked on carbon fibre, to examine the process in detail; the programme was subsequently called the Genesis project. Although Courtaulds was under financial pressure at that time and several research programmes were cancelled, senior managers could see that the new process might be a way of reinvigorating the cellulosic fibres business (see Appendix 2 for a description of the solvent spinning process.)

The first laboratory-scale production began in 1981, and it was scaled up to a small pilot plant in 1983.[28] A note to the Board from the research department commented that the process looked extremely promising "in the sense that we believe it should be possible to produce a fibre with properties superior to viscose at lower cost…If we can succeed, this project could confound the conventional wisdom that there will be no new high volume fibre before the end of the century. It offers the possibility of transforming the prospects of our cellulosic fibre business".

Courtaulds hired American Enka's former research director, Bill Mathis, as a consultant. He confirmed that Courtaulds had taken a different approach to that taken by Enka and had solved

[28] For a description of the process see Appendix Three.

some of the scaling-up problems. Courtaulds subsequently decided not to acquire an American Enka licence; it was regarded as expensive and unnecessary since White and his team were making good progress without it. Yet there were still many technical issues to be resolved.[29] One was to achieve a high recovery rate for the solvent which was much more expensive than the chemicals used for viscose. Another was to find a stabiliser to prevent the solvent from degrading and discolouring the cellulose. There were also difficulties in developing machinery that could dissolve the cellulose in a reliably continuous way. The published Enka route using extruders proved unsuitable for volume production. Courtaulds found an alternative route, using a Kraus Maffei horizontal mixer, and this was used in the pilot plant. It was later discovered that a more suitable machine was a vertical mixer, known as a filmtruder.

The greatest challenge lay in developing a spinning system that would produce usable fibre in sufficient volume and good enough quality to make the whole process economic. Spinning on the laboratory scale was satisfactory but when the pilot plant started operation it took many months before it produced more than a very small amount of fibre. As Pat White recalled, 'We started by thinking we could use existing spinning technologies from polyester, then we changed to acetate, and finally we ended up having to design the whole spinning module from scratch. This included developing new jet hole punching technologies and jet holder designs.' [30] Another problem was fibrillation, the splitting of a single fibre filament into microfibres, which needed to be carefully controlled if fabric of satisfactory quality was to be produced.

By the time the pilot plant came on stream, some of these problems were on their way to being ironed out; the plant was enlarged to produce nearly one tonne a week. With the Genesis project now generating enthusiasm among senior executives, the decision was taken to build a semi-commercial plant at Grimsby at a cost of some £8m. Although this did not commit Courtaulds to full-scale production, there was now a real possibility that Genesis, both because of its properties as a fibre and because of its clean manufacturing process, might eventually take over from viscose as a mainstream cellulosic fibre.[31]

In making the case for this investment the Fibres Division pointed out that the new fibre was different from and in most respects superior to regular viscose. 'The properties of the yarns and fabrics produced indicate that both dry and wet strengths are very high indeed for a cellulosic fibre. Because of its high wet strength Genesis is particularly suitable for non-wovens which will be an early target market. In textiles the strength properties create opportunities for use in blends with polyester, acrylic and cotton as well as 100 per cent Genesis applications. The initial sales strategy will be to position Genesis as a superior quality, high performance fibre with properties that justify a 30 per cent price premium over viscose staple.'

In 1988 the company decided on a name for the new fibre, Tencel (based on tenacity and cellulose), and it hoped to persuade the industry's standard-setting body, BISFA (Bureau International pour la Standardisation des Fibres Artificiels), to approve Tencel as the generic name for all solvent-spun cellulosic fibre, but this was not accepted. BISFA adopted the word lyocell (drawn from the Latin word lyo, meaning 'I make liquid') as the generic name. While Courtaulds kept the Tencel name, the word lyocell would be used as the generic name for both staple fibre and filament yarn, and for any other applications that might be developed such as plastics or films.

Lenzing's approach to lyocell

Courtaulds was not alone in looking for alternatives to the viscose process. Lenzing, the Austrian company, was aware of the early research undertaken by Eastman Kodak and later by American Enka, and was watching with some anxiety Courtaulds' apparent success in improving the solvent spinning process. Unlike Courtaulds, Lenzing in the 1980s was a one-factory company and overwhelmingly dependent on viscose. It was more confident than Courtaulds about the future of viscose; it had already improved the process so that most of the chemicals could be re-used and the damage to the environment reduced. Yet, if there was even a possibility that viscose might one

[29] For an account of how Courtaulds developed the process, see Patrick White, 'Lyocell: the production process and market development', in Woodings (ed) *Regenerated cellulose fibres*

[30] Interview with author, 24 November 2006

[31] Sipko Huismans, who as chief executive of Courtaulds from 1991 to 1996 was an enthusiast for Tencel, saw solvent spinning as a far more elegant way of making cellulosic fibres than viscose, which he once described as 'a horrific, antediluvian process'. *Chemical and Engineering News*, 1 June 1987

day be displaced by lyocell, Lenzing could not afford not to make the new fibre. Thus the decision to initiate research into solvent spinning and later to take a licence from Akzo was in part in defensive measure.

By 1990 Lenzing's research had reached the point where it could begin to consider a commercial-scale plant. It had also filed a number of patents, one of which related to the filmtruder, the device that had been adapted by Courtaulds as a mixer in the solvent spinning process. This was central to a patent infringement suit which Lenzing launched against Courtaulds in 1993, leading to lengthy litigation between the two companies which was eventually settled in 1997.

The patent suit showed that Lenzing was taking lyocell seriously and had no intention of leaving the field clear for Courtaulds. Yet its initial move into full-scale production was cautious. Instead of adding lyocell to the Lenzing site, it chose to build a small plant, with a capacity of 20,000 tonnes a year, at Heiligenkreuz in Burgenland, near the Hungarian border. (Lenzing's financial commitment was reduced by the availability of regional grants from the European Commission.) The plant was authorized in 1995 and came on stream two years later. The fibre was marketed as Lyocell by Lenzing, later Lenzing Lyocell

The first Tencel plant

Meanwhile, Courtaulds had been pushing ahead fast. The pilot plant in Grimsby had worked well, and there was no doubt in the minds of Tencel's supporters that the next step was to build a full-scale plant, either at Grimsby, next to the existing acrylic fibre plant, or at Mobile, Alabama, which was the site of a Courtaulds rayon factory. The case for going ahead was that Courtaulds had a technical lead in a product that not only had distinctive properties as a fibre but was also the only man-made fibre that could be produced from renewable resources by an environmentally friendly process.

When members of the Group Executive considered the proposal in April, 1990, they had before them a study from McKinsey, the management consultants, which supported the project. According to McKinsey, there would be sufficient demand, initially in industrial rather than textile markets, to absorb the output of the first plant at an acceptable price. Tencel's high wet strength and absorbency would make it very suitable for wipes and other disposable products. One member of the Executive was doubtful, on the grounds that Tencel was a high-risk project with an uncertain payback. He acknowledged that Tencel was a potentially attractive fibre with some advantages over viscose, but it was not as novel or distinctive as polyester and nylon had been when they were introduced and sales projections were bound to be speculative. Spending on Tencel would absorb cash at a time when Courtaulds was trying to expand in non-fibre industries. In his view alternative strategies for Tencel should be considered, including partnership or licensing.

Despite these objections the majority of the committee took the view that Tencel was too good an opportunity to forgo. Apart from the merits of the new fibre, the project had the attraction of being based on in-house research and linked to Courtaulds' long-established expertise in cellulosic fibres; it should be less risky, and less difficult to manage, than an acquisition. The initial plan was for the plant to be built at Grimsby, and the company hoped to get a government grant to support this investment. When the application was turned down, attention switched to Mobile. The state of Alabama was keen to attract the project and willing to offer financial support. The proposal was approved by the Board and the ground breaking ceremony at Mobile took place in September 1990. Production was scheduled to start in the summer of 1992, with an initial capacity from two production lines of 18,000 tonnes a year.

When the plant came on stream in 1992, much of the initial demand came, not from the US, but from Japan. The Japanese textile industry, looking for profitable niches in the market to offset the loss of commodity business to imports, found that the fibrillating characteristics of Tencel could be used to produce high-quality fabrics, principally denim, with an unusual peach-like texture, and customer reaction was enthusiastic. With the aid of an Osaka-based consulting firm, Courtaulds organised a club of spinning, weaving and finishing companies, chosen on the basis of their technical and commercial competence and their willingness to invest in the machinery needed to process Tencel efficiently.[32]

Although Tencel was sold in Japan as a premium fibre, its success there suggested that the textile qualities of the new fibre would be more important than had been predicted when the Mobile plant was approved The McKinsey study had forecast that the main demand would be industrial, with apparel acting to some extent as a filler. The change of emphasis was expected to work to Courtaulds' advantage, since the apparel market offered higher margins and should be quicker to develop than the industrial market; extensive testing would be necessary before Tencel could be used, for example, in medical applications.

Looking further ahead, senior executives in Courtaulds believed that, as the market for Tencel was widened, it might eventually replace viscose staple as a mainstream cellulosic fibre. The expectation was that cotton prices would tend to rise as the land available for cotton growing was switched to food production; there would be a 'cellulosics gap' which could only filled by a man-made fibre. Since further investment in viscose staple was likely to be constrained by tighter environmental rules, Tencel might replace it and take some of the cotton market. There was speculation that Tencel could be as important for man-made fibres as Pilkington's float glass invention had been for the flat glass industry. That process, by eliminating the labour-intensive grinding and polishing stage, had transformed the economics of glass-making. Pilkington patented the process in 1959 and subsequently granted licences to most of its competitors.[33] The view in Courtaulds was that Pilkington had made a mistake in its licensing policy; Courtaulds, at least for the next few years, should keep Tencel to itself.

At first Courtaulds did not seek to patent its work, believing that it made more sense to protect its technology as trade secrets; there was also some uncertainty as to whether it would be able to secure valid, enforceable patents. Its principal advantage was the know-how it had acquired in developing Tencel and that was expected to provide at least five years' advantage over any competitor. But with patent offices now granting patents more liberally and a more aggressive approach to patenting by other fibre producers, this policy was changed. Courtaulds filed some 40 patents of its own and in 1990, as a precautionary move before starting on the Mobile project, it secured a licence from Akzo.

More Tencel capacity

Sipko Huismans, who had taken over from Sir Christopher Hogg as chief executive in 1991 (Hogg remained as non-executive chairman until 1996), was convinced that Tencel was the biggest opportunity that Courtaulds had had for decades, and that it would be the foundation for corporate renewal. At the end of 1993 he brought forward a proposal for a second plant at Mobile, raising capacity from 18,000 tonnes to 43,000 tonnes. The outside directors, concerned that the project might be going ahead too fast, raised a number of questions: over the projected trend in prices, whether the forecast profit margins were achievable, and whether the outcome of the patent dispute with Lenzing might be less favourable than was assumed in the proposal. Gordon Campbell, the director responsible for fibres, argued that the assumed price premium which Tencel would have over viscose (roughly $1.25/lb against $1.00/lb) was realistic. He also said that, in the unlikely event of Lenzing winning the patent suit, the worst that might happen would be the retroactive imposition of a royalty of 3 per cent or less and this would not seriously affect profitability. None of these points, in Campbell's view, undermined the case for moving quickly to a second plant and this was accepted by the Board.

At the end of 1994 Campbell put up a proposal for a European Tencel plant, to be built at Grimsby, and this time he found the Board harder to convince. All the directors accepted that the attractiveness of Tencel as a textile fibre was now firmly established, but capital costs were too high and there were still unresolved problems in dyeing and finishing. The issue was whether Courtaulds should commit itself to another new plant when the Mobile expansion was not yet on stream and the future growth of the market was uncertain. One director commented that £100m

[32] For an account of the marketing arrangements in Japan, see Helen Perks and Richard Jeffery, 'Global network configuration for innovation: a study of international fibre innovation', *R & D Management*, Vol 36, No 1 2006

[33] G.F.Ray, 'Float glass', in L.Nabseth and G.F.Ray, *The diffusion of new industrial processes*, Cambridge 1974

was a large throw at this early stage of the project. He wondered whether it would be better to expand capacity at the existing US plant, and in smaller steps. Another pointed out that the investment in Tencel would reach £250m within two years and would only start generating a return in 1997-98; there was a danger that Tencel would starve the rest of Courtaulds of capital.

A clinching argument for going ahead, in Campbell's view, was that Lenzing had just announced its intention to build a lyocell plant in Austria. Campbell argued that Courtaulds would be at a serious disadvantage in the European market if it deferred a European plant. He also assured the Board that the demand projections on which the Grimsby proposal was based were conservative, even on the assumption that prices were kept relatively high. This was accepted by the Board, with some reservations, and construction work at Grimsby began early in 1995, with production due to start in 1997.

The priority now was to improve the economics of the process and to bring down capital costs. A new Tencel plant was estimated to cost about $4500-4700 per annual tonne of capacity compared with $2900-3000 for viscose and $2000 for polyester. The target was to get costs down to about $2500 but this was not easy since most of the equipment used in the Tencel process was standard and could not easily be modified. At the processing stage, better control of fibrillation was essential if the range of Tencel applications was to be extended from the peach-like fabrics which had been such a hit in Japan. To make the best use of Tencel required specialised dyeing and finishing technology which could only be justified if the processor could be sure of getting a high price for the fabric. This was a particular problem in the US where the dyeing and finishing trade was less sophisticated than in Japan and more geared to the mass market. A non-fibrillating version of Tencel, called A100, was under development but it would not be available until 1998.

Quite apart from fibrillation, Tencel was more difficult to process than standard viscose. Courtaulds no longer had its own textile mills (as it had when rayon was introduced) but the Tencel marketing team used one of the finishing mills in the sister company, Courtaulds Textiles (which had been demerged in 1990), as a test bed to help iron out the processing problems. David Wilkinson, the executive in charge of Tencel marketing, considered buying this mill, and doing what Courtaulds had done in the 1930s when it bought the Arrow Mill to show Lancashire cotton spinners how to process viscose staple. Courtaulds later decided not to invest directly in its own dyeing and finishing facilities but to work with the established companies. Wilkinson put in place a comprehensive marketing programme built around a select group of spinners, weavers and garment makers in each major country. Advice was taken from a former DuPont manager who had been involved in marketing Lycra. Marketing centres were established in Japan, South Korea and Brazil as well as in the US and the larger European countries.

These efforts kept Tencel sales moving forward until the end of 1996. By that time the initial surge in Japan had slackened but Tencel was gaining ground in Europe and the US, and sales were running at an annual rate of just over 30,000 tonnes, about equally divided between the three regions. This was a tiny amount in the context of a world fibre market running at an annual rate of over 40m tonnes, but the view in Courtaulds was that Tencel could be much more than a specialist fibre. In a presentation to the Board, Wilkinson said that the fibre had the versatility to penetrate over 20 fabric categories within the apparel fibre market (Table 12). These included knitwear, jersey knits, worsted/wool look fabrics and denim. There were also opportunities in non-woven products such as wipes and medical fabrics, a market that Courtaulds had not yet addressed.

Table 12 Tencel: the market opportunity

Worldwide demand for fibres exceeds 40m tonnes annually

25m tonnes in apparel
9m tonnes in household textiles
6m in industrial applications

Of the 25m tonne apparel market lyocell has the potential to compete for between 3m and 4m tonnes

In the 6m tonne industrial market lyocell is a potential substitute for viscose (300,000 tonnes) and for long staple cotton.

Household textiles are likely to become more important in the future but remain as a lower priority for the next few years.

Source: Courtaulds presentation October 1997

At a time when other parts of the company were performing poorly, Tencel was increasingly seen, inside and outside the company, as the jewel in its portfolio. "I invest in Courtaulds", one investor remarked, "because I want to invest in Tencel". The new fibre was a major theme in Hogg's final statement to shareholders. Tencel, he believed, would be as important to the future of the company as rayon had been at the start of the century: "The company can go into the next century having found what it has been looking for since the 1940s, namely a secure basis for long-term growth – a basis, furthermore, which is absolutely rooted in what Courtaulds has been doing for most of its history. It is the task of every generation of management to take the best things in its inheritance and shape them so as to survive healthily the creative destruction of the capitalist process. Tencel is fully in keeping with that endeavour".[34]

Such was the enthusiasm of the Tencel team that even before the Grimsby plant had come on stream consideration was being given to an Asian plant. Although no detailed planning for Asia was done, and there were questions about how such a plant would be financed, the ultimate aim was to have Tencel capacity of 50,000 tonnes in each of the three main regions, North America, Europe and Asia.

All this depended on maintaining the momentum of Tencel sales. At the end of 1996, for the first time in the project's history, demand began to weaken. Several factors were at work: over-stocking in Japan, the onset of the Asian economic crisis, a fashion swing away from denim, and the fact that prices of other fibres, especially viscose and polyester, were falling. Sales continued to fall throughout 1997 and, although the start-up of the Grimsby plant had been delayed by construction problems, Courtaulds found itself with too much Tencel capacity on its hands.

The setback in Tencel was one of the factors, along with poor results from the rest of the fibres business, which was depressing the company's share price. By early 1998 it had fallen to a point where the paints business on its own was worth more than the stock market value of the whole company. This was the opportunity spotted by Akzo Nobel, which was looking for ways of enlarging its paints business. In April, 1998 it announced a takeover offer for Courtaulds, which was accepted by the Board. The Dutch acquirer was only interested in the paints business, but it also had also a sizeable fibres business of its own. It was put together with Courtaulds' fibres into a new company, Acordis. The initial intention was to float Acordis on the stock market as an independent company. Instead it was sold to CVC, the private equity firm.

Tencel after the Courtaulds takeover

In the immediate aftermath of the takeover demand for Tencel continued to run below capacity and part of the Mobile plant was temporarily shut down. However by the end of 1999, as the Asian economies recovered, the market improved. Over the next three years the ex-Courtaulds Tencel team remained in place, now working for CVC but pursuing the same strategy as before the change of ownership. The A100 non-fibrillating version of Tencel was introduced, and was well accepted in the market. The Tencel team also developed non-woven applications - industrial and technical wipes, and medical fabrics such as gauzes - where the biodegradability of the fibre was an advantage.

CVC's initial plan was to improve the profitability of Acordis to the point where it could be floated on the stock market or sold to a trade buyer. The most obvious buyer, or partner, was Lenzing, and in 2001 CVC reached agreement with Bank Austria, Lenzing's principal shareholder, on a merger of the two companies. This would have created a large Austrian-based company with a big stake in lyocell and a range of other, mainly cellulosic, fibres, but the deal was barred by the European Commission on competition grounds. At the end of 2003 CVC put forward a new proposal, to separate Tencel from the rest of Acordis and to sell it to Lenzing, and this deal went through in the following May.

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[34] Courtaulds Annual Report 1995-1996.

The purchase was a risk for Lenzing, since Tencel was not yet profitable and demand might not be sufficient to keep all three lyocell plants – Grimsby, Mobile and Heiligenkreuz in Austria – fully employed. But Thomas Fahnemann, an ex-Hoechst manager who had joined Lenzing as chief executive in 2003, was convinced that, as a cellulosics specialist, Lenzing could not afford not to be in the lyocell market, and that the existing plant at Heiligenkreuz was not adequate on its own as a base for expansion.[35] Moreover Tencel had been far more successful in the marketplace than Lenzing Lyocell; the fibre coming out of the Heiligenkreuz plant was rebranded as Tencel soon after the takeover had gone through, and this helped to boost sales.

Lenzing was enthusiastic about the new fibre, describing it in a company brochure as having opened a 'new age' in fibre technology. Tencel, it said, unites the advantages of many different fibres: '…as fine as silk, as strong as polyester, as easy to care for as acrylic, cool and pleasant like linen, as warm as wool and absorbs more moisture than cotton.' The Austrian company recognised the quality of the work, both on the technical side and in marketing, that Courtaulds had put into the new fibre; several members of Courtaulds' technical team and a few senior managers accepted offers to move to Lenzing.

Since the takeover Lenzing has sought to broaden the market for Tencel. The initial focus in Japan in the early 1990s had been on Tencel as a luxury fibre that could create new fabric finishes. But the fashion market is notoriously fickle (the vogue for peach touch did not last) and Lenzing has successfully promoted Tencel for use in home textiles, non-wovens, active sportswear and workwear. Tencel is still seen as a speciality fibre, but as sales and production have increased the price differential between Tencel and viscose has come down.

Like Courtaulds Lenzing has not invested in the direct marketing of Tencel to the consumer, but it has put more emphasis on building long-term relationships with its customers in the textile trade. It relies on a network of spinning mills to feed Tencel into the supply chain and to work with fabric mils to facilitate the use of the fibre. The aim is to get as many garments and other items as possible labelled as Tencel as possible; there is a labelling programme whereby garment manufacturers who purchase a registered Tencel fabric can apply for free Tencel labels for all the garments they are making. The company has also been putting more marketing effort behind Tencel in China and India. These countries are now seen as consuming markets rather than just as processing facilities to make products for Western markets.

Lenzing believes that for at least the next 20-30 years there will be a market for both viscose and Tencel. In some textile applications the properties of Tencel are not required and in some non-woven products viscose outperforms Tencel. However, in Europe and the US any expansion of cellulosic fibre capacity is likely to be based on Tencel rather than viscose. This was confirmed in 2010 when the company announced plans to build a new Tencel plant, with a capacity of 60,000 tonnes a year, on the Lenzing site. Together with expansion at the three other plants – Heiligenkreuz, Grimsby and Mobile – this will increase the company's total Tencel capacity from 140,000 tonnes to some 280,000 tons by 2015.[36] The demand for Tencel in Asia has been rising, but Lenzing prefers to supply that market through exports from Europe and the US; there are no plans to build a Tencel plant in Asia, not least because of fears that the technology might leak out to its Asian competitors.

Because of the continuing strength of viscose demand in Asia, viscose will continue to account for the bulk of Lenzing's worldwide production over the next few years but Tencel's share will rise to nearly a quarter (Table 13).

Lenzing's faith in Tencel, and in cellulosic fibres generally, has been reinforced by recent trends in the world fibre market: the growing demand for "green" products that are made from natural materials and cause no environmental damage; the surge in cotton prices in 2011 which caused spinners to look for alternative fibres with cotton-like characteristics; and the high oil price which has increased the price of synthetic fibres. World production of cellulosic fibres, which had been a static or declining trend from the mid-1970s to the end of the 1990s, has been increasing in the last few years, rising from less than 2m tonnes in 2000 to a new peak of 4.6m tonnes in 2011.

The Lenzing story is a triumph of specialisation. In the 1950s and 1960s Courtaulds was by far the largest European producer of cellulosic fibres, but it lost faith in viscose and for that and other

[35] Interview with author, April 30, 2008

[36] The ex-Courtaulds Grimsby plant is likely to remain at a capacity of 40,000 tonnes; it has been adapted to specialise mainly in A100 non-fibrillating fibre.

reasons diversified in other directions; viscose capacity was drastically cut back. The development of Tencel revived Courtaulds' interest in cellulosics, but by the time Tencel came on the market the company's financial position was weak. It came to look on the new fibre as an answer to the company's short-term problems, not as a product which would take many years to develop. Although Lenzing came to share much of Courtaulds' view of Tencel, its approach to the lyocell market was more cautious. Tencel was seen as adjunct to a still viable viscose business, not as a replacement for it.

Table 13 Lenzing's expansion plan

Fibre sales in 2011		Planned capacity in 2015	
705,000 tonnes		1,185,000 tonnes	
Of which:		Of which:	
Viscose	450,000 (64%)	Viscose	765,000 (64%)
Tencel	135,000 (18%)	Tencel	280,000 (23%)
Modal	120,000 (17%)	Modal	140,000 (13%)

Table 15 Lenzing fibre sales in 2011 (% of total)

Asia	57
Europe incl Turkey	33
Americas	7
Other	3

Source: Lenzing

What did Courtaulds do wrong?

It is ironic that Tencel, once seen as the basis for Courtaulds' renewal, was a factor contributing to the company's demise. Was this outcome due to bad luck or bad management? Some errors were certainly made in the course of the project. It was probably a mistake to have entrusted the design and construction of the Tencel plants to the company's in-house engineering firm, Courtaulds Engineering. This company had built several fibre plants in Eastern Europe in the 1960s and 1970s, but it had little recent experience in fibres. Capital costs might have been lower if Courtaulds had used an engineering contractor such as Zimmer in Germany, but senior managers were worried that the use of an outside company might cause Tencel know-how to leak to its competitors.

The processing problems, partly linked to fibrillation, were also underestimated in the early stages of the project. The enthusiastic response to Tencel in Japan, after the first Mobile plant had come on stream, may have misled Courtaulds into thinking that the same success could soon be replicated in other markets. The amount of effort and investment that was needed to widen the market – both at the manufacturing stage and in the whole textile chain from fabric to retailer – was greater than was anticipated in the early 1990s.

However, even if these problems had been recognised earlier, the growth of Tencel might not have been greatly accelerated. Technical setbacks of this sort have occurred in virtually every new fibre launch and Courtaulds' response in the Tencel case, even if belated, was vigorous and effective. In contrast to carbon fibre, there was no fundamental deficiency in the properties of Tencel as a fibre.

In the end, under different ownership, Tencel achieved part of what the proponents of the project in Courtaulds had hoped for, but they were too optimistic about the timescale. Lenzing was more cautious in its view of how quickly lyocell might become a mainstream fibre, and less pessimistic about the future of viscose. The Austrian company never lost faith in the viscose process and improved it to the point where the environmental problems were largely eliminated. This required some costly investment which Courtaulds might have been unwilling to undertake but, once completed, it gave the viscose plant at Lenzing a new lease of life.

What went wrong with Tencel was not that the technical and marketing teams made serious errors but that the project was pushed ahead too fast. The decision to build the plant at Grimsby in 1995, understandable in the light of the expected competition from Lenzing, came at a time when the future growth of the market was uncertain. Several directors were uneasy about the decision as were some members of the Tencel development team. They thought that any new investment should be made at Mobile, where the infrastructure was already in place, rather than splitting production between two sites.

Another strand in Courtaulds' thinking had been that world supplies of cotton would be constrained by the availability of land. As it turned out, cotton production continued to increase during the 1990s and early 2000s, thanks partly to improved productivity and partly to continued subsidies to cotton producers, especially in the US. Yet this situation has changed radically in the last few years, with cotton prices rising to very high levels in 2011. While some special factors were at work in that year, it seems likely that, because of the lack of suitable land, the scope for increasing cotton production will diminish. Thus there will be a "cellulosics gap" as Courtaulds had predicted, and a man-made alternative will be needed.

As for what sort of fibre will fill the gap, Courtaulds may have been right in thinking that in the long run lyocell would take the place of viscose staple, at least in Western Europe and North America. Lenzing came to share this view, at least to the extent that any expansion in cellulosics that Lenzing might undertake in Europe or the US would be based on Tencel rather than viscose. The situation in Asia was different because environmental rules were less stringent and viscose might be acceptable for longer. Indeed, there was an unexpected surge in Asian viscose demand in the early 2000s, mainly based on the growing popularity of polyester/viscose blends in China. As incomes rose, creating a bigger demand for cooler and more comfortable clothes, Chinese consumers seemed to prefer the softness and absorbency of viscose-based fabrics, whereas the trend in the West had been in favour of pure cotton or cotton-rich fabrics. Volumes were still small compared to polyester, but the strength of demand provided confirmation that Lenzing's confidence in viscose had not been misplaced.

5. Conclusion

One lesson from the carbon fibre and Tencel stories is that launching a new fibre and establishing it in the market almost always takes longer than expected. Persuading customers to switch to the new product calls for patience, commitment, and a willingness to live with periods of low or negative returns while production costs are brought down and quality deficiencies ironed out. Even DuPont, the industry's outstanding innovator, was not immune to these problems. Nylon, the first of the synthetic fibres, was an overnight triumph but with Orlon (acrylic) and Dacron (polyester) DuPont could not simply invent the new fibre and wait for sales to materialise. It had to study much more closely what customers wanted. 'During the 1950s and 1960s the variables of consumer desire – fashion, style and taste – triggered a sustained campaign in DuPont's Textile Fibers Department to get in touch with end-use customers.'[37] Lycra, the spandex fibre launched in 1959, made meagre returns until the mid-1960s. Ten years later Lycra accounted for twenty per cent of the Fibers Department's profits; it proved to be one of the most successful of all DuPont's fibres. Kevlar, the high-strength fibre used in bullet-proof vests and other demanding applications, took even longer to take off. Commercial production began in 1971; nine years later *Fortune* magazine described it as '…a miracle in search of a market.'[38] It was not until the mid-1980s that Kevlar began to earn an adequate profit.

To make headway in carbon fibre, especially in aerospace, a lot of money had to be spent over a long period to improve the product and to widen the market. That was not forthcoming at Courtaulds, perhaps because carbon fibre was seen within the fibres division as marginal to the high-volume textile fibres that provided the bulk of its profits. Carbon fibre did not have a champion at the top of the company and, even if there had been one, he or she would have found it difficult to overcome the growing impatience among senior managers at the failure of the business to fulfil its early promise.

[37] Regina Lee Blaszczyk, 'Styling synthetics: DuPont's marketing of fabric and fashions in post war America', *Business History Review*, 80, 3, October 2006
[38] *Fortune*, 1 December 1980.

Tencel, by contrast, did have top-level champions in Sipko Huismans, Gordon Campbell and others, and they were supported by their chairman, Sir Christopher Hogg. From the start of the project to the Akzo Nobel takeover in 1998 there was never any reluctance on the part of the Courtaulds Board to provide the funds that were needed for product development. The problem was not lack of enthusiasm but rather an over-reliance on the new fibre, because of problems in other parts of the company, as the main source of profits growth.

How far is this impatience for early returns comparable to the way Courtaulds handled carbon fibre? It is striking that the ultimate winners both in lyocell and in carbon fibre were firms that were under less pressure than Courtaulds to meet the short-term expectations of shareholders. Lenzing in Austria and the Japanese companies were operating in a business environment that favoured continuity. Lenzing was obliged to maintain employment at its Austrian site, and it had a strong incentive to stick with viscose, to improve the manufacturing process, and to develop new cellulosic fibres; it had neither the resources nor the incentive to diversify in the way that Courtaulds did.

Toray did diversify, but not, like Courtaulds, by making large acquisitions in unrelated industries; it used the skills and technology that it had developed in fibres to move into plastics, films and other sectors where those capabilities could be put to good use. Moreover, it continued to invest in its original business, fibres and textiles, by searching for better quality and new products and by creating an international network of factories; its aim, largely achieved, was to play a similar role in the global textile chain to the role that it had traditionally performed in Japan.

It is hard to avoid the conclusion that, at least in the two industries discussed in this paper, the Anglo-American system has some disadvantages. This is not to say that "short-termism" was the sole or even the most important reason for the disappearance of Courtaulds as an independent company. The company made mistakes, both in the handling of the carbon fibre and Tencel projects and more generally in its strategic decisions.[39] It must also be said that Japanese long-termism can lead companies to stick too long to low-return businesses, and slow down the necessary redeployment of resources from slow-growing to fast-growing sectors of the economy. If there are too many acquisitions, mergers and divestments in the UK and the US, there have been too few in Japan.

What does seem clear, nevertheless, is that in industries which require patient, long-term investment, in which technological change is incremental rather than radical and in which technical excellence is crucial, ownership and governance arrangements of the sort which prevailed at Toray and Lenzing constitute a competitive advantage.

Appendix 1 *Estimated output of leading man-made fibre companies in 1978*

Company	**Output (000 tonnes)**	**Composition of output (%)**				**% of total sales from fibres**
		Rayon/ Acetate	**Nylon**	**Polyester**	**Acrylic**	
DuPont	1840	1	31	60	8	33
Akzo	660	42	29	27	2	37
Toyo Rayon	545		36	49	16	75
Courtaulds	541	62	6	5	27	47
Rhône Poulenc	431	22	34	34	10	16
Celanese	418	24	12	64	-	57
Monsanto	416		51	16	33	16
Teijin	404	2	11	87	-	70
Hoechst	336	16	1	68	16	8

[39] The biggest mistake was the plunge into textiles and clothing in the late 1960s and early 1970s, creating an assortment of low-return businesses which greatly complicated top management's task in the subsequent decade.

Asahi Kasei	272	13	21	2	64	44
ICI	240	-	40	60	-	8
Snia Viscosa	212	40	32	7	21	50
Montedison	189	12	16	22	50	18
Bayer	160	-	22	16	62	4
Lenzing	115	90	-	-	10	74

Sources: These figures are estimates drawn partly from T.A.J. Cockerill, The man-made fibres industry: international comparisons of structure, conduct and performance, Unpublished PhD thesis, University of Manchester 1985 (Tables 3.9 and 9.10),and partly from industry sources.

Appendix 2 *Fibre manufacturing processes*

The viscose process

Purified cellulose, usually derived from woodpulp, is steeped in an aqueous solution of sodium hydroxide. This produces alkali cellulose, which is reacted with carbon disulphide to form sodium cellulose xanthate. The xanthate is then dissolved in dilute sodium hydroxide to yield a viscous orange-coloured solution called viscose, which is filtered and ripened to the desired coagulation point appropriate for spinning. The rayon filaments are formed when the viscose solution is extruded through the spinneret into a spin bath consisting of sulphuric acid, sodium sulphate, zinc sulphate and water.

The solvent spinning process (lyocell)

Purified cellulose is dissolved in a solution of hot N-methyl morpholine oxide (abbreviated to NMMO). The solution is then extruded (spun) into fibres and the solvent extracted as the fibres pass through a washing process. The manufacturing process is designed to recover over 99 per cent of the solvent. The solvent itself is non-toxic and all the effluent produced is non-hazardous.

Source: Based on Calvin Woodings, 'A brief history of regenerated cellulosic fibres', in Calvin Woodings (ed), *Regenerated cellulose fibres,* The Textile Institute 2001