Sustainable Development for Engineers

A Handbook and Resource Guide

Edited by
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Greenleaf
PUBLISHING
2006

5 Technology: the culprit or the saviour?

Many critics have argued that technology is the root cause of the lack of sustainability in society.[1] Their argument assigns the key role in the development of the problems of the modern world to technology:

> People's lives become more and more dominated by technology, without offering the possibility of influencing it. Therefore, technology should be halted in order to return to a more natural world. Every attempt to spur innovation for sustainable technologies is doomed to futility, or could even make things worse as technological domination will increase and (unforeseen) side effects of technology will exacerbate the situation.

However, the history of technology also presents another picture: the social world is not dominated just by technology but is also actively engaged in shaping new technology. Technologies were shaped in conflicts such as those between workers and employers, and reflected the moral, social and political orders of the time.

We need a leap in the environmental efficiency of our production of goods and services. Technological change must therefore be at the heart of sustainable development. This chapter explores the role of technology in society and its relation to science—as science and technology have become strongly interrelated.

1 For example, the philosophers Habermas and Marcuse. Also more recently: E. Braun, *Futile Progress: Technology's Empty Promise* (London: Earthscan, 1995) and K. Sale, *Rebels Against the Future: The Luddites and their War on the Industrial Revolution* (Reading, MA: Addison Wesley, 1995).

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The most profound changes in the way we deal with science and technology took place over the past 500 years. We focus on this period in the opening section and then offer some theoretical reflections.

Technology and science in human history

Medieval technology

Humans have developed various technological means to support themselves. In the Middle Ages, technological 'progress' diffused only very slowly. The case of papermaking (Figure 5.1) serves as an illustration.

> The basic features of modern papermaking technology were created in China in the early 2nd century AD. In the early 7th century, papermaking reached Korea and Japan. In the 8th century, it reached Samarkand in Central Asia. The technology was established in the Muslim world in the 10th century and in the 11th and 12th in Christian Europe, where it was initially denounced as a technology of the Muslim foe. This attitude remained essentially unchanged until the introduction of the printing press in the 15th century, when paper finally became accepted in Western Europe.[2]

Innovations that would today reach every corner of the world within a few years spread only very slowly, if at all, in medieval times. This is only partly due to slower methods of transport and limited communications. Neither was the slow pace of technological change due to a lack of individual inventiveness. The Christian resistance to papermaking illustrates another feature of medieval society. In a society that sought its solace beyond earthly life, technological change was considered relatively unimportant. European medieval thinking on how nature and society were ordered stressed the importance of objects and people remaining in their 'allotted place'. Financial prosperity through technological innovation was not encouraged. As long as new technology could be absorbed within existing institutions, it was more or less tolerated—being sought actively only in times of sheer despair such as starvation, conquest or flooding.

Technology was part of the world of craftsmen. Craftsmen were generally free men living in medieval towns where they were organised in guilds that protected their interests (see Chapter 4). To be able to execute their craft, they often needed a licence from the local lord. Craft workers generally took great pride in their craft, becoming apprentices at the age of 11 or 12. This apprenticeship lasted for about seven years.

2 Paperonline; www.paperonline.org/index.html, 9 November 2005.

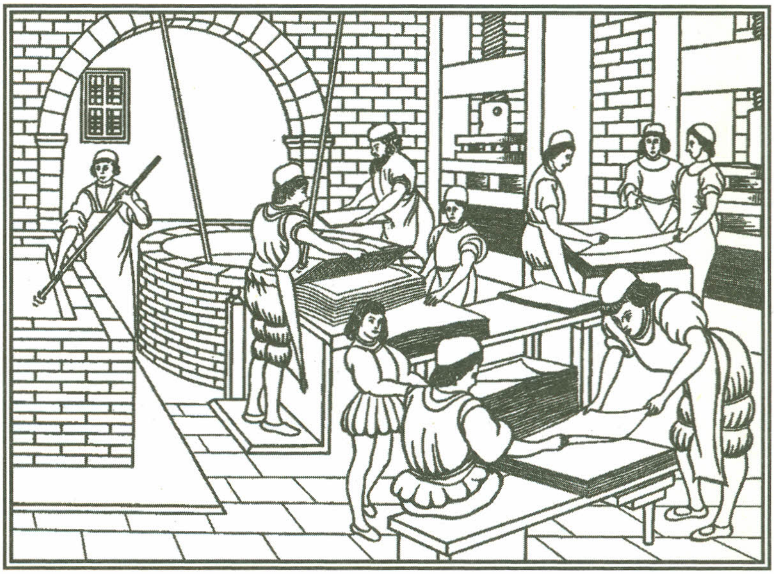


FIGURE 5.1 Medieval papermaking

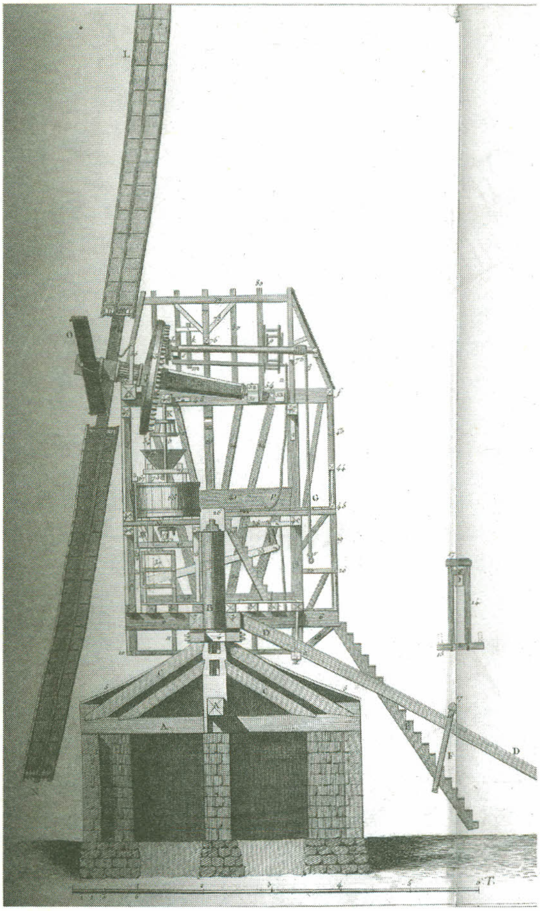
Source: www.st-armand.com/Images/200412_CoursPapier.gif, 9 November 2005

Science within medieval Christianity had a very different background. It encompassed the search for truth as a means of better understanding God's creation. It had nothing to do with pure curiosity or with the wish to improve the destiny of humankind. Philosophy was directed towards finding proof of God's existence and solving apparent inconsistencies, e.g. between God's perfection and the apparent imperfections in the universe. The study of law was aimed at reconciling commercial practice and divine law. Sciences that we regard today as empirical and experimental such as botany, physics, astronomy and physiology were part of philosophy. They were directed towards explaining God's divine works and not to practical utilisation.

The ordinary craft workers had nothing in common with this science. Such knowledge was of no value to them. The scientists belonged to the social world of the rulers of that time, i.e. the nobility, clergy or successful merchants.

As explained in Chapter 4, medieval competition was stifled by the structure of economic production, i.e. agricultural production by a peasantry dependent on the nobility and production of a narrow range of goods by craft workers organised in a guild system. The general result was the maintaining of tradition rather than spurring innovation for a 'better' future.

Technological change did occur, but mainly as a result of outside influence and in those societies where the old 'divine order' was challenged most. Thus, Crusaders probably brought the windmill (Figure 5.2) to Europe in the early 13th century. The windmill was of great advantage in lowlands that



Source: Diderot et d'Alembert, *Recueil de Planches sur les Sciences, les Arts Liberaux et les Arts Méchanique, avec leur explication* (Paris, 1762)

FIGURE 5.2 Medieval windmill type (note the straight wings)

lacked water power. But the technology diffused only slowly because of its impact on social structure, which upset the nobility's traditional milling rights. In the north-west European lowlands, however, the windmill became an increasingly popular and effective means of pumping water. With sea levels rising and agricultural peatlands setting after centuries of use, these countries were in dire need of pumping power. In these areas, windmill-driven pumps were not introduced primarily to expand economic activity but to protect agriculture from deteriorating natural conditions. Later on, population growth prompted a need for agricultural expansion and, with most arable land already in use, windmills opened the way for 'reclaiming' new land.

The Renaissance

European medieval science was rather backward in comparison with the scholarly works of the Islamic world of that time. The classic Greek works were studied in the Islamic centres of learning but hardly at all in Europe. Physiology, philosophy and mathematics reached European scholars particularly through interaction with the Spanish centres of Islamic learning, which were conquered in the 14th and 15th centuries during the Reconquista.

The study of the divine order became more and more empirically oriented. For example, the Danish nobleman Tycho Brahe became famous for his detailed astronomical observations.[3] Inconsistencies appeared and scholars dared to propose interpretations of their own which were not in accordance with the interpretations of the church. For example, the Polish scholar Nicholas Copernicus proposed a heliocentric cosmology.[4] Galileo Galilei's defence of this system culminated in his well-known clash with the Pope: in 1633, the Inquisition convicted Galileo for his heretical theories.

It is not by chance that this clash coincided with the great religious divide within European Christianity. The values that were underlying this split—empiricism, rationality and individual conviction—divided the institutions of Christianity and remained points for debate within the churches.

The changes that took place in the Renaissance (14th–16th centuries) had a tremendous influence on the social climate for technology. Society was more geared towards the individual, who could try to obtain power, property and status. The striving of intellectuals for individual expression included the active design of new machines; we know this, for example, from the extensive drawings of Leonardo da Vinci.[5]

The changes also fuelled a drive to discover the world, facilitated particularly by new, superior techniques of shipbuilding and navigation. This led to a series of famous discoveries such as the discovery of:

- America by Columbus in 1492
- The sea route from Europe to India by the Portuguese Vasco da Gama in 1497
- The first tour around the world by Ferdinand Magelhaes[6] in 1521

An early example of the application of science to technology can be seen in Galileo's work around the turn of the 17th century. Galileo was the first to

3 es.rice.edu/ES/humsoc/Galileo/People/tycho_brahe.html, 9 November 2005.
4 *De revolutionibus orbium coelestium* was published in 1543 just before Copernicus died.
5 The machines of Leonardo da Vinci can be seen in the National Museum of Science and Technology, Milan, Italy (www.museoscienza.org/english/leonardo/invenzioni.html, 17 March 2006) and the Chateau du Clos Lucé, Parc Leonardo da Vinci, Amboise, France (www.vinci-closluce.com/machines.htm, 17 March 2006).
6 Magelhaes died during this tour, but one of his five ships returned safely to Spain.

show that, if air resistance is disregarded, the acceleration of a falling body is independent of its mass. This allowed him to calculate the parabolic orbits of projectiles. The resulting tables proved to be a powerful tool for gunners, enabling them to determine accurately the firing angle needed to hit any target at a given range.

The new empirical science reached a peak in Isaac Newton's mechanical theory. Newton's theories were able to explain planetary motion and terrestrial movements using the same set of equations. Newton and Leibniz independently developed the calculus[7]—a powerful mathematical tool for every modern engineer.

Newton's theories helped in navigation and the development of new instruments for navigators, helping Britain to achieve maritime domination. However, science and technology were 'living apart together' in the 17th and 18th centuries.[8]

Most technology remained predominantly based on traditions that were passed on by apprenticeship. The universities did not have a dominant role in the scientific changes that led to Newtonian mechanics; they remained dominated by classical scholars and frequented by students from the nobility and landed gentry.

Scientific and technological progress

In the 18th century, it was still rare for the results of scientific experiments to be exploited commercially in the form of new or improved products and processes. Technological changes that could, in principle, be calculated by mechanical theories were developed mainly by practical craftspeople without any theory. Although Dutch windmill-builders improved their designs during the 17th century, e.g. by adjusting the angle of the windmill sails along the shaft of the sail (Figures 5.3 and 5.4), their efforts were not based on scientific principles.

It was not until 1759 that John Smeaton corroborated the value of the 17th-century changes in windmill design when he presented results of the first scientific experiments on windmill sails in his *On the Construction and Effects of Windmill Sails.*[9]

A number of key technologies were created long before their underlying scientific principles were formulated. For example, the invention of the first

7 British and continental scientists have long argued on priority claims for this invention.

8 R.S. Westfall, *The Construction of Modern Science* (Cambridge/New York/Melbourne: Cambridge University Press, 1971); T.S. Kuhn, *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought* (Cambridge, MA: Harvard University Press, 1957).

9 John Smeaton, *On the Construction and Effects of Windmill Sails: An Experimental Study Concerning the Natural Powers of Water and Wind* (Philosophical Transactions of the Royal Society of London, 51; 1759): Pt 1, 138-74.

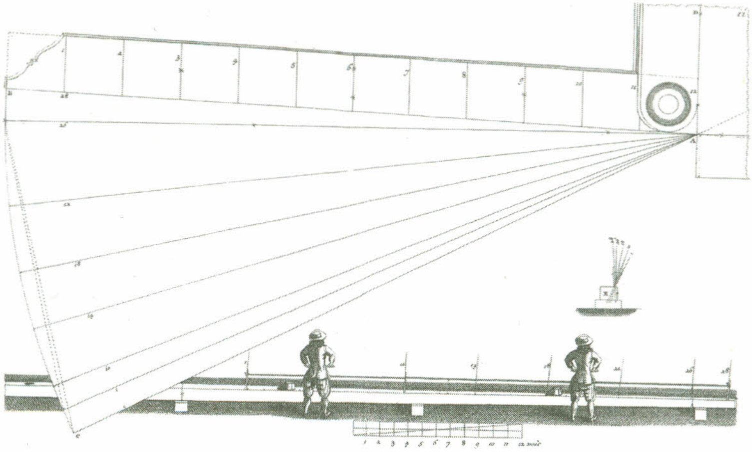


FIGURE 5.3 Drawing showing the angles of a sail on a wing shaft

Source: *Groot Volkomen Molenboek* (Amsterdam, 1734)

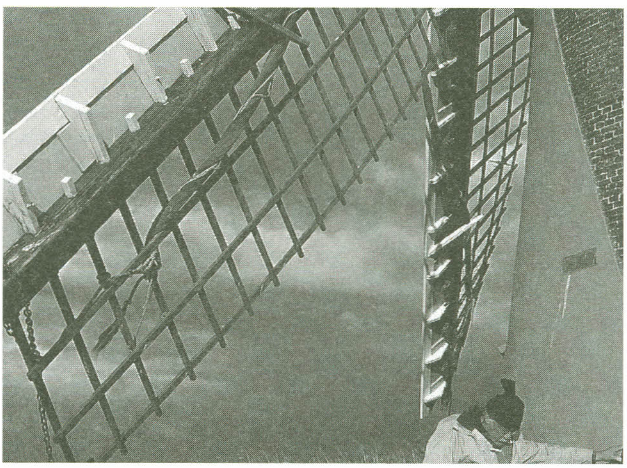


FIGURE 5.4 Wing of a windmill (the changing angle of the sail to the shaft is clearly visible)

Source: home.wanadoo.nl/flikkenschild/laeker/molenwiek79.htm, 9 November 2005; © Erik Flikkenschild, Oegstgeest

steam engines[10] preceded the formulation of the thermodynamic principles explaining their operation by more than a century.[11] As L.J. Henderson penetratingly wrote in 1917:

10 By Newcomen in 1712 (see Chapter 3) and Watt in 1770.
11 By Carnot in 1824 and Joule in 1845.

> Science is infinitely more indebted to the steam engine, than is the steam engine to science.[12]

The Enlightenment (18th century) can be seen as the closing phase of this changing relation between science and technology. Its basic philosophy of rationalising society implied that technology should be freed of its guild-based rules and traditions of craftsmanship. The French philosopher Condorcet (1743–94) introduced the idea of 'progress'.

- In science, it implied an improved understanding on the causes of nature
- In technology, it implied constructing more and better artefacts to improve human domination over nature

For us, this might sound pretty obvious. However, for 18th-century Christianity and other religions, the idea of seeking progress in life was strange. Rewards for conduct were only to be received *post mortem*.[13]

Science was moving only very gradually away from religious dogma. Before Charles Darwin published *On the Origin of Species* in 1859, biologists based their science on theological assumptions. A good example is the answer to the question how old is the Earth: in 1800, Archbishop James Ussher established the year of origin as 4004 BC.[14]

Before the 19th century, the process by which technical innovation came about was generally one of trial and error. As failures were often dramatic, there was a strong reluctance to change technologies. Churches, for example, were constructed according to rules of thumb that had remained unchanged for centuries.[15] Discovering that a construction would be unstable was a disaster given the enormous investments that medieval cities made in building these structures. A notable example of this is the bell tower of the cathedral in Pisa, Italy (Figure 5.5).

The nation-states that took shape in the 18th and 19th centuries transformed European economies, shifting their basis from local autarchy to

12 L.J. Henderson was the first president of the History of Science Society. See: L.J. Henderson, *Henderson on the Social System: Selected Writings* (Chicago: University of Chicago Press, 1970).

13 Christians could deserve heaven by good conduct or remorse of sin. Hindus could reincarnate as a higher being.

14 D. Nelkin, *The Creation Controversy: Science or Scripture in the School* (New York: W.W. Norton, 1982): 25-26.

15 Though modern technology sometimes pretends that its rigour is completely proven in advance by scientific means, unexpected problems can still arise. Bridge construction, for example, is still in part trial and error, sometimes leading to unforeseeable failure. In 1996, the city of Rotterdam had to close its new Erasmus Bridge because of oscillations set up by the wind in the suspension cables. Similarly, pedestrian-induced oscillation in 2000 of the London Millennium Bridge necessitated its closure and substantial reconstruction.

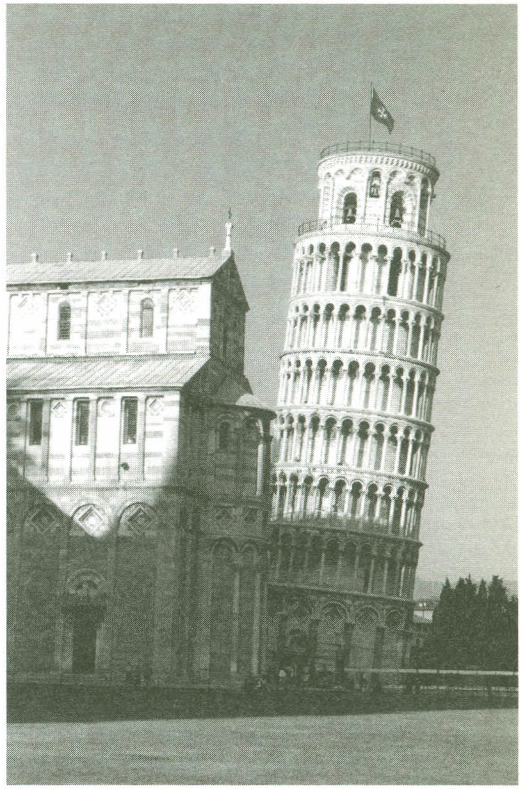


FIGURE 5.5 Leaning Tower of Pisa

national and imperial trade. This transformation required a variety of civil works such as:

- Railways
- Canals
- Roads
- Bridges
- Water control and management systems

In addition, machinery and factories had to be designed to supply large quantities of goods efficiently.

These technologies were not designed according to local circumstances (the practice of the medieval craft workers), but were designed using the universal rules of science. The substitution of tradition by rationality promoted in the 19th century led to a need for a new profession—the engineer.

Engineers were not traditionally trained craft workers but people who were trained scientifically to design and operate technologies according to rationalist principles. For example, the 1847 founders of the Dutch Royal Institute of Engineers[16] explicitly required its members to be trained scientifically.

Engineering schools were first founded in France, e.g. the École des Mines in 1783.[17] Later in the 19th century, engineering schools were established throughout Europe and the USA. As generally the only predecessors of the new engineers were the military engineers engaged in artillery and the construction of fortresses, the new engineers were called 'civil engineers'.

By the end of the 19th century, the 'social issue' dominated the public debate: industrial production had created an urban proletariat and sharp social conflict. Many engineers were sympathetic to political visions in which the state was assigned a leading role in advancing social justice. For a profession that had gained its status by rationalising infrastructure and production, rationalist planning of economic activities was a highly attractive proposition. An example of thinking in terms of industrial progress is shown in Figure 5.6.

This also was evident in the 1920s and 1930s when various sources of energy (electricity, coal, oil, town gas) became available. Many engineers started arguing for rational (state) planning of these energy sources as the competition between them was often creating inefficiencies in infrastructures. In general, the engineering profession of the first half of the 20th century was committed to solving society's problems through rationalised planning. The progress of engineering was well fitted to the progress for which the socialist movement, in particular, was striving for.

Techno-science

Although engineers were scientifically educated, academic scientists did not regard them as colleagues. Polytechnic colleges and institutes were often not allowed to grant doctorates and their social status was much lower than that of universities. However, this view changed as the polytechnics often trained excellent scientists, e.g. Albert Einstein graduated in 1900 from the Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology) in Zurich. Universities in the 19th century concentrated on the classics. The natural sciences generally dealt with phenomena that were interesting, but without any practical use. Industry and trade usually had little interest in the scholarly activities of universities.

This changed first in chemistry. In Germany, chemists developed processes to manufacture synthetic dyes based on coal tar. Bayer AG in Leverkusen was the first company to develop a research laboratory for the scientific study of chemistry in order to create new chemical products. How to do research and how to organise it within the context of industry was itself an

16 Koninklijk Instituut van Ingenieurs (KivI); www.kivi.nl, 9 November 2005.
17 www.ensmp.fr/Fr/ENSMP/Histoire/histoire.html, 9 November 2005.

FIGURE 5.6 Stained glass window at the Industrial School of Terrassa (Spain) constructed in 1902

Source: *L'escola Industrial de Terrassa 1902-2002, cent anys de vida universitaria* (Lourdes Plan I Campderros, 2002)

innovation.[18] Competing chemical companies soon followed Bayer's example.

By 1890, the electrical inventions of Thomas Edison led to the birth of the electric industry. Research was needed to provide improvements and the General Electric Research Laboratory in Schenectady, New York, emerged. This laboratory acquired fame following the award of the Nobel Prize in chemistry to Irving Langmuir in 1932.

18 G. Meyer-Thurow, 'The Industrialisation of Invention: A Case Study from the German Chemical Industry', *ISIS* 73.268 (1982): 363-81.

The creation of nylon

At the end of 1926, Du Pont decided to undertake a fundamental research programme. One of its main proponents, Charles M.A. Stine, later explained the motives:

> Fundamental research assists one to predict the course of development of chemical industry. Pioneering applied research enables one to achieve certain objectives indicated by fundamental research. Therefore, the continued growth (as distinct from mere expansion) of the chemical industry is dependent upon fundamental research. That is the basic philosophy of fundamental research.

Stine stated that fundamental research also improved industry–university interaction and created consulting specialists for applied research within the company. The main difference to university research would be that:

> In university research, the discovery is a sufficient objective in itself . . .

Du Pont recruited academic scientists and gave them the freedom to engage in the subjects they thought could be useful. In 1928, Wallace Hume Carothers (Figure 5.7), a chemist from Harvard University, was enlisted as head of the organic chemistry group. For a long time, Carothers was doubtful about taking this step because industrial research was not valued highly by academics. At Du Pont's Experimental Station, he started research on the macromolecular concept of polymers—a subject of great

Courtesy: Hagley Museum and Library

FIGURE 5.7 Wallace Hume Carothers

interest and a focal point of debate in chemistry at that time. Carothers made new, long-chain polymers by carrying out well-understood chemical reactions. A flood of publications emerged from this research project that demonstrated that polymers were just ordinary molecules, only longer.

Initially, Carothers was supposed only to carry out fundamental research and Du Pont encouraged the publication of his results. However, new managers in 1930 urged Carothers to focus his research on developing new products based on polymers. He did not resist this pressure. His main concern was the freedom to publish. This was granted to him if he was willing to give the company time to patent applications for his discoveries.

In September 1931, Carothers announced the possibility of obtaining useful fibres from strictly synthetic materials. In July 1935, Du Pont chose to commercialise polyamide-6,6 because the raw materials were comparatively cheap and, at the end of 1937, it was produced in a pilot plant.

The technological problems of production were enormous. The required purity of raw materials was unprecedented and the spinning process differed considerably from conventional processes. About 230 engineers worked on the project and more than 200 patents were granted just for the technological work.

At the end of 1938, Du Pont launched 'nylon'. It was an overwhelming success on the market. Du Pont could not fulfil demand during World War II due to the military demand for nylon parachutes. Nylon stockings disappeared from the market only to return with even greater success after 1945.

The spirit in which Carothers led his team was described by one of the members of his group, the later Nobel Prize winner Paul Flory:

> His approach to science was motivated by boundless curiosity; it was not fettered by superficial boundaries between specialties.

Carothers did not live to see the success of nylon. He committed suicide in April 1937, deeply depressed and, although the first industrial chemist to be admitted as a member of the National Academy of Science, convinced of having failed as a scientist.

Scientists such as Carothers bridged the gap between academics and industrial technologists. As Harvard president James B. Conant said of Carothers' acceptance of a position at Du Pont:

> . . . he had facilities for carrying on his research on a scale that would be difficult or impossible to duplicate in most university laboratories.

Source: somewhat abbreviated from K.F. Mulder, 'Replacing Nature: The Arising of Polymer Science and Synthetic Fibre Technology' in B. Gremmen (ed.), *The Interaction between Technology and Science* (Studies in Technology and Science, Vol. 3; Wageningen, the Netherlands: Wageningen Agricultural University, 1992): 239-62

The Du Pont Corporation of Wilmington, Delaware, in the USA set up a chemical research laboratory. Du Pont made a fortune during World War I following the invention of its smokeless gunpowder during the late 19th century. Du Pont decided to continue this successful strategy by carrying out even more fundamental research. However, the frictions between academic and industrial research were still partly unresolved.

The history of nylon discovery at Du Pont serves as an interesting example of techno-science in the making.

Science has proved its value to industrial and military interests. Scientific research became the first stage of the development of new products and processes.

During World War II, physicists in the USA suspected that Hitler was working on a German nuclear bomb. They convinced Einstein to ask US President Roosevelt to set up a research project to also develop a nuclear bomb. In the Manhattan Project, top physicists were gathered to build such a bomb. The first ever nuclear explosion took place on 16 July 1945 at the Trinity test site in the Alamogordo Desert, New Mexico, USA (Figure 5.8).

The Japanese cities of Hiroshima and Nagasaki were the first targets of nuclear attacks on 6 and 9 August 1945 respectively.[19] Physics had lost its innocence.

Nowadays, the natural sciences not only contribute to technology. Technology also plays a major role in carrying out science: supercolliders in particle physics, the Hubble space telescope, supercomputers and high-resolution microscopes are technologies without which modern science would be impossible.

Technocracy

New problems emerged in the industrial market economies in the second half of the 20th century. With large parts of society effectively rationalised, many people felt alienated by the complexity of the technological systems that they were part of. Industrial production was often organised according to Frederick W. Taylor's 'scientific management' methods, which implied that production was cut into small tasks that were assigned to a single labourer. The tasks of the labourer were measured and goals for his production were set. In 1913, Henry Ford was the first to combine Taylor's approach with the moving assembly line to produce the Ford Model T. In this way, an unskilled labourer, making just exact copies of one specific part, replaced the craftsman that made every part to fit.

19 There have been many discussions about whether the bombing of these two cities could have been prevented by the demonstration of a nuclear bomb to the Japanese. For the role and views of scientists: see the short biography of Robert Oppenheimer, director of the Manhattan project (www.pbs.org/wgbh/aso/databank/entries/baoppe.html, November 2005) or R. Jungk, *Brighter than a Thousand Suns: A Personal History of the Atomic Scientists* (New York: Harcourt, Brace & Co., 1958).

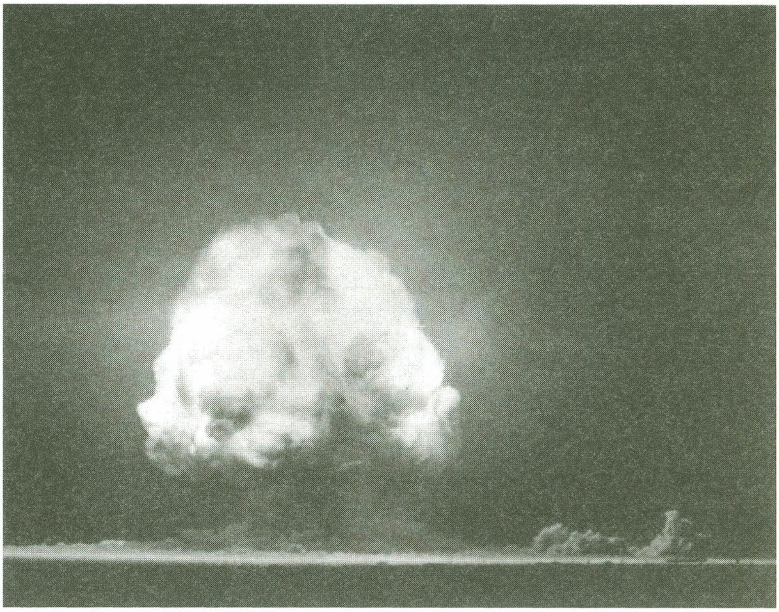


FIGURE 5.8
Trinity test site—12 seconds after the first nuclear explosion on 15 July 1945

Source: www.lanl.gov/orgs/pa/photos/historical.html, 9 November 2005; © The Regents of the University of California, 1998–2003

Vast extensions of cities were needed to supply the growing urban population with housing and to improve the living conditions of the lower classes. Rationalised spatial planning provided for efficient use of indoor and outdoor space. However, this method of spatial planning led to a heavy-handed uniformity of the built environment.

But criticism grew from the 1960s. Workers and their trade unions criticised the stupefying character of assembly-line labour.[20] Environmental pollution, ecological destruction and resource depletion became increasingly evident and were deemed to be 'the price of progress'. The progress in military technology led to the creation of weapons of mass destruction, which even created the risk that humankind could extirpate itself.

Although initially specific technological products were criticised for their detrimental impact, 'technology' itself was soon under attack. 'Technological thinking' was accused of being based on a principle of domination over both nature and people. Western societies were accused of being 'technocracies', i.e. governed by expert knowledge.

The technocratic attitude was condemned as:

- Undemocratic in that it sought to control people rather than interact with them

20 Charlie Chaplin's film *Modern Times* is a beautiful criticism of the assembly line.

- Short-sighted in that intensive and exponentially growing use of natural resources and production of waste and emissions were bound to end in catastrophe

Engineers and their technologies were not only blamed for creating these substantial problems, but were also more generally accused for harming society. This led to engineers becoming far less committed to social issues and, instead of the social engagement of the first half of the 20th century, engineers tended to retreat from society in the second half. Many engineers regarded politics as irrational and politicians as only seeking their own re-election instead of the common good.

The controversy on nuclear energy that took place in almost every industrial country starting from the beginning of the 1970s exemplifies this perspective. To provide for the projected growing demand for energy, there was no other option then to build nuclear power plants. This progress came at the expense of:

- The unsolved problem of nuclear waste
- The risk of unprecedented accidents
- The risk of spreading the technology for manufacturing nuclear arms
- Threats to liberty caused by measures to counter risks of attack on nuclear installations

Large numbers of people did not agree with this sacrifice. Meanwhile, it turned out that the growth in energy consumption in most countries was not as large as had been anticipated. The controversy that emerged came to an end with the meltdown of the Chernobyl nuclear reactor in 1986 (Figure

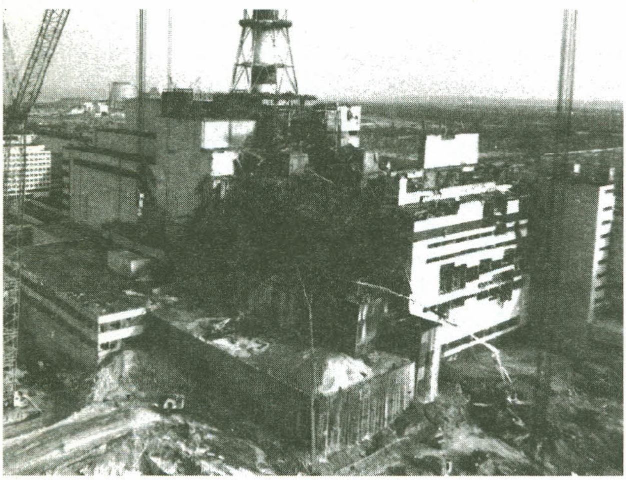


FIGURE 5.9 **Chernobyl reactor**

5.9).[21] The technocratic argument that there was only one solution to provide society with energy had failed.

Having grown used to criticism from environmentalists, engineers did not jump on the issue of sustainability when it was introduced by the Brundtland Commission in 1987 (see Chapter 1). Although sustainable development might equally well have been interpreted as a new challenge to the engineering community, many engineers regarded the notion as suspicious and were concerned that it might mean a new attack on their profession.

Over the past decade, there have been some promising initiatives to once again harness engineers and their skills in addressing the challenges facing society such as sustainable development. Will engineers be able to contribute to sustainable development but avoid the pitfall of technocratic domination of nature and people?

Below we examine concepts regarding the relation between science, technology and society.

What drives technological change?

Many people regard technology as self-evident. It is just there and it is the most efficient or convenient way to fulfil a need. But why was it developed? Was it a stroke of luck, of ingenuity, or was it determined by the state of the economy? Can outsiders or even technologists themselves influence the future course of technology towards sustainability? Or are these attempts futile, as the course of technological change is beyond anyone's control?

Technological determinism

One of the most outspoken critics of modern technology was the French philosopher Jacques Ellul (1912–94). Adopting a historical perspective, Ellul sought to understand how medieval technologies differed from the technologies spawned by the rationalist attitudes of 20th-century engineers. In his view, they did so in a number of salient respects. Medieval technologies were:

- Restricted in their sphere of application—technologies were often based on specific local resources and therefore rarely transferable
- Dependent on limited resources and on well-developed skills such as making and repairing tools, or judging weather conditions and tides

21 See, for example: www.chernobyl.co.uk, 9 November 2005.

- Local in character—technological solutions to specific problems were embedded in local culture and tradition

Together, this meant that individuals and local communities were able to influence and shape the technologies they applied. There was, in other words, a degree of technological choice.

According to Ellul's analysis, modern technology has quite a different set of characteristics:

- Automatism. There is just one 'best' way to solve each particular problem and the accompanying technology appears to be compelling across the planet
- Self-perpetuation. New technologies reinforce the growth of other technologies, leading to exponential growth
- Indivisibility. The technological way of life must be accepted completely, with all its upsides and downsides
- Cohesion. Technologies used in disparate areas have much in common
- Universalism. Technologies are omnipresent, both geographically and qualitatively

For Ellul, this meant that modern technology destroys human freedom. In his view, the future of humankind was bleak and there was no way back.

Some of Ellul's basic lines of argument can be recognised in the 'Unabomber Manifesto'. In the 1980s and early 1990s, Theodore Kaczynski—a mathematician and terrorist known as the Unabomber—launched a series of attacks on US airlines and research institutes. In his Unabomber Manifesto, he explained that it was possible for individuals to participate in modern society only if they accepted its technologies. Although these technologies were often legitimised as creating more freedom, the Unabomber argued that they in fact took away more and more of our freedom because they proved to be increasingly compelling for the individual. In the vision of the Unabomber, this would ultimately lead to the destruction of human freedom. And in his view, too, there was no alternative and no way back.[22]

But, in their analysis, Ellul and the Unabomber fail to acknowledge the tremendous advantages that technology has brought us. The number of people living a relatively good life on planet Earth (i.e. well nourished and healthy) is historically unprecedented. Criticising the alienation created by technology as Ellul and the Unabomber did is one-sided, to say the least, and therefore leads to unjustified conclusions. We indeed sacrificed some liberties but, in return, received new ones. Moreover, the debate on nuclear energy proves that the course of technology is not a path leading to an inevitable destiny. Social preferences will be reflected in technologies, espe-

22 www.thecourier.com/manifest.htm, 10 March 2006.

Unabomber on technology: Unabomber Manifesto, paragraph 127

A technological advance that appears not to threaten freedom often turns out to threaten it very seriously later on. For example, consider motorised transport. A walking man could formerly go where he pleased, go at his own pace without observing any traffic regulations, and was independent of technological support systems. When motor vehicles were introduced, they appeared to increase man's freedom. They took no freedom away from the walking man, no-one had to have an automobile if he didn't want one, and anyone who did choose to buy an automobile could travel much faster than the walking man. But the introduction of motorised transport soon changed society in such a way as to greatly restrict man's freedom of locomotion. When automobiles became numerous, it became necessary to regulate their use extensively. In a car, especially in densely populated areas, one cannot just go where one likes at one's own pace; one's movement is governed by the flow of traffic and by various traffic laws. One is tied down by various obligations: licence requirements, driver test, renewing registration, insurance, maintenance required for safety, monthly payments on purchase price, etc. Moreover, the use of motorised transport is no longer optional. Since the introduction of motorised transport, the arrangement of our cities has changed in such a way that the majority of people no longer live within walking distance of their place of employment, shopping areas and recreational opportunities, so that they have to depend on the automobile for transportation. Or else they must use public transportation, in which case they have even less control over their own movement than when driving a car. Even the walker's freedom is now greatly restricted. In the city he continually has to stop and wait for traffic lights that are designed mainly to serve auto traffic. In the country, motor traffic makes it dangerous and unpleasant to walk along the highway. (Note the important point we have illustrated with the case of motorised transport: When a new item of technology is introduced as an option that an individual can accept or not as he chooses, it does not necessarily remain optional. In many cases the new technology changes society in such a way that people eventually find themselves forced to use it.)

Source: www.thecourier.com/manifest.htm, 9 November 2005

cially when citizens engage in the debates instead of leaving these issues to experts.

The reasoning of many technological optimists is rather similar to that of Ellul and the Unabomber as they often paint a picture of a high-tech future as if this future were not human-made, but an inevitable reality.

A typical line of argument goes as follows:

- The pool of scientific knowledge is growing continuously
- The development of technology can utilise ever more scientific knowledge and other technologies
- This will lead to better technologies (which will in turn stimulate scientific growth and the development of other technologies)
- Citizens have to adapt to these new technologies

This kind of reasoning (whether optimistic or pessimistic) is called **technological determinism**: the state of technological development determines the nature of a society rather than vice versa. The technological deterministic view of the world is reflected in such historical characterisations as the 'Stone Age', the 'Bronze Age' or the 'age of the automobile'.

Technological determinism is questionable. It assumes that the relationship between science, technology and society is only unidirectional. As the example of the steam engine shows, technology results not merely from the simple application of scientific principles. Various analyses show, moreover, that the creation of new technologies is not a process with a single ('optimum') outcome, as Ellul holds, but is the result of a process of choice—a characteristic Ellul claimed only for traditional technology.[23] However, technological determinism cannot be rejected completely.

Social constructivism

Technological determinism is completely rejected in the social construction of technology (SCOT) model. In this model, technologies are considered to be social constructions, i.e. technologies have been given shape by the demands of various social groups. Central to this view is the notion that people can attribute different meanings to the same artefact (human-made object). The car, for instance, might be a means of transport for its owner, but it is also an object to demonstrate status or lifestyle. For pedestrians, the car may mean danger and, for administrators, it may mean an object for taxation.

Various groups may therefore try to influence the development of the technology in different directions. These might sometimes coincide but might also lead to controversy.

Technological artefacts possess certain stability, as they are building on past experiences and existing knowledge. Changes in technology will therefore not coincide with sometimes rapidly changing demands in society, but rather lag behind. The reverse also occurs: society adapts itself to the possi-

23 There are other forms of determinism that reduce processes of change to one single factor. One might argue for instance that Marxism contains a form of socio-economic determinism reducing history to class conflict: K. Marx, 'The History of All Hitherto Existing Society is the History of Class Struggle', *Communist Manifesto* (1848).

bilities that new technologies offer, but these adaptations may take decades (e.g. the use of computers by older people).

These delays create a dynamic pattern of technology–society interaction. As many technologies fail and certain demands of society cannot be fulfilled, a co-evolutionary pattern of development emerges.

For the constructivist, the stability of technological artefacts is explained by the stability of the social preferences in society. The SCOT model is explained further in Chapter 9.

The debate between 'constructivism' and 'determinism' is not just of scholarly interest. For technological determinists, attempts to influence science and technology for commercial, ethical or political reasons are futile, producing no more than minor ripples in the pond. For social constructivists, society is constantly deciding on the future shape of technologies (even people that claim to be technological determinists). For social constructivists, shaping technologies for sustainable development is a realistic track to pursue.

Technological determinism and social constructivism as recurring stages

Between these two rather extreme positions, concepts have been developed that aim to integrate the determinist's main assertion (i.e. technology is self-propelling) with that of the constructivist (i.e. technology is the outcome of socially determined choice). These new conceptions seek to account for the conditions under which:

- Technological change is propelled predominantly by social forces
- Social forces can scarcely influence that process

Stability of technologies can be explained by the various different environments in which technologies are embedded:

- **Socio-economic environment**: a technology must meet the demands imposed on it by all the relevant social actors in its environment (for a car: price, status, comfort, safety, appeal, speed, etc.). New technologies must, in other words, solve the problems that actors think can be solved by the artefact in question
- **Physical environment**: every artefact is adapted to other artefacts, technological infrastructure, maintenance systems, energy sources, etc. For example, cars must fit on roadways, use available, standardised fuels, be fitted with familiar steering mechanisms and meet various performance standards before they are approved. New technologies must be compatible with these existing conditions
- **Technological knowledge base**: technologies are based on existing know-how, rules and accepted paths for further innovation that are

accepted within a particular technological community. New technological artefacts arise from the state of knowledge and the shared beliefs regarding possible improvements within the community of practitioners designing and constructing them. More radical technological change therefore implies changing mainstream ideas within technological communities or breaking their power by creating an alternative technological community to take its place

Since major upheavals in all three realms rarely occur simultaneously, radical innovations are likewise rare. For example, an alternative for the car should be socio-economically viable (in terms of costs/performance ratio) and adapted to the existing infrastructure (roads, fuel, regulation, etc.). We should also have the ability to design it.

The various forces favouring technological stability mean that technological artefacts generally change only incrementally and over long periods of time. As in biological evolution, however, a technology may become extinct or split into several species adapted to specific niches and circumstances.

In the large-scale technological systems of today, social institutions and technological hardware form a seamless web and any distinction between the 'social' and 'technological' dimensions of these systems becomes futile. Particularly when systems fail, attempts are made to blame casualties on either 'human' or 'technological' factors. Such attempts are doomed to failure, though, for it is in fact impossible to distinguish the human and technological factors in any given technological system. Is it the hardware that is not properly adapted to the humans operating, administering or maintaining it, or are the humans not functioning in accordance with the demands set by the hardware they are dealing with?

Technological changes are sometimes slow and can easily lag behind the rapid pace of change in society as a whole. However, the creativity of technologists also leads to new products and systems that revolutionise social life such as mobile phones and computers. This is not to say that every new revolutionary technology is accepted by society. Indeed, many new technologies were not accepted and are hardly remembered. Civil aircraft with vertical take-off and landing, or soluble tablets to replace toothpaste are just two of the vast array of technologies that have been rejected. In the case of nuclear power, the issue of acceptance has still not been settled.

It might therefore be argued that, in so far as technology can be distinguished from its social environment, the relationship between them is a (co-)evolutionary one—they adapt to one another, but there are many mismatches. Such mismatches occur especially in times of rapid change, due either to massive breakthrough of new technologies, as in the case of information technology (IT) in the 1980s, or to rapid changes in society's preferences.

The technologies applied to solve environmental problems are products of:

- The present and the past

- Society's norms and values
- Technologists' experiences and paradigms

They shape our common future while reflecting contemporary standards and interests. To develop the technologies that humankind needs for sustainable development is therefore not only a formidable challenge for technologists, but for our entire technology-dependent civilisation.

Technology ideology and responsibility

Political choice and controversy

Decision-making with respect to technologies is probably more important for the long-term future of society than any other political issue today. Although technologies are not very often in the media focus (apart from major accidents), the decisions that are made in their design, development and introduction are crucial for the future of society.

Decisions on technology are not neutral. Technology is a political issue and so are sustainable technologies. For example: one might seek the solution of the environmental problems created by current agricultural practice either in organic farming (requiring large areas) or in extensive high-tech farming such as so-called pig factories (being highly efficient, with low emissions, but removing animals from their natural environment).

However, new technologies are very often not recognised as political issues requiring due debate.

Striking examples of political technologies are the extraordinarily low overpasses over the Parkways on Long Island, New York, which have as little as nine feet clearance.[24] They were deliberately designed and built that way by Robert Moses, the master builder of New York from the 1920s to the 1970s. He built his overpasses to discourage the presence of buses on his parkways. These reasons reflect his social class bias and racial prejudice. Car-owning whites of the 'upper' and 'comfortable middle' classes, as he called them, would be free to use the parkways for recreation and commuting. Poor people and blacks, who normally used public transit, were kept off the roads because the 12-foot-tall buses could not handle the overpasses. One consequence was that racial minorities and low-income groups had limited access to Jones Beach. Moses made doubly sure of this result by vetoing a proposed extension of the Long Island Railroad to Jones Beach.

24 L. Winner, *The Whale and the Reactor: A Search for the Limits in an Age of High Technology* (Chicago: University of Chicago Press, 1986). This example is derived from: R.A. Caro, *The Power Broker: Robert Moses and the Fall of New York* (New York: Vintage, 1975).

If the political nature of technological decisions becomes evident, technology becomes the focal point of debate. But, because the political nature of technological decisions is often hidden, this is often after official decisions have been made. Public controversies are a nuisance to decision-makers, but they are highly important for the democratic quality of the decision-making process. Controversies stimulate the scrutiny of the arguments and hence improve the clarity of the subject among the public.[25]

In these controversies, the **control dilemma** is often important. According to Collingridge, decision-makers on technologies are caught in a 'control dilemma':

> attempting to control a technology is difficult, and not rarely impossible, because during its early stages, when it can be controlled, not enough can be known about its harmful social consequences to warrant controlling its development; but by the time these consequences are apparent, control has become costly and slow.[26]

One of two main ways to solve this problem is by attempting, in the design phase, to gain insight into (side) effects occurring later on. This is, according to Collingridge, a dead end. Historical examples show that the attempt to predict all side effects is doomed to fail. Collingridge thus proposes an alternative way, which gears itself towards the design phase and attempts to integrate the idea that decisions have to be made based on (partial) ignorance. Hence technologies should be flexible. But what should they be flexible for? Very often the norms and values for evaluation of the effects are also unclear and could shift over time.

Public controversies can contribute to a better understanding of a technology and its effects. Various reports covering all kinds of technological details are written during such events, but these reports rarely aim to discuss or exchange arguments. The contestants generally try to discredit each other by pointing at unsound expertise and to prove the interests or ideological basis of their opponents.[27] In practice, such controversies are never decided by techno-scientific arguments.

However, a sound techno-scientific argumentation is a precondition for public and political credibility. Technological controversies are sometimes decided by politicians but, as politicians are often made to feel insecure by keen debate in society as well as among experts, controversies often either

25 See for example: A. Mazur, *The Dynamics of Technical Controversy* (Washington, DC: Communications Press, 1985) and A. Rip, 'Controversies as Informal Technology Assessment', *Knowledge: Creation, Diffusion, Utilisation* 8 (1986): 350.

26 D. Collingridge, *The Social Control of Technology* (London: Pinter Publishing, 1980).

27 Such an analysis regarding the role of physicists in the nuclear energy controversy in Austria was made in: H. Nowotny, *Kernenergie: Gefahr oder Notwendigkeit? Anatomie eines Konflikts* (Frankfurt am Main, Germany: Suhrkamp, 1979).

end with external developments such as the nuclear accident at Chernobyl or they gradually disappear.[28]

The responsibility of engineers and scientists

Scientist and engineers have considerable responsibility in public decision-making on techno-science. They are often the first to recognise the dangers to the public of new techno-scientific developments. For example, the discussion on the dangers of DNA research was started by scientists. Robert Pollack, a US virologist was the first to voice concerns to his colleagues; this led to a letter of warning published in *Science* in 1974.[29]

Moreover, as expertise gives credibility to viewpoints in the public debate, it is important that underprivileged groups such as non-governmental organisations (NGOs) and citizens' initiatives also have access to scientific expertise. 'Science shops' can play an important role in this. These small units (generally within universities) can offer the scientific expertise needed by NGOs and citizens' groups.[30]

The public responsibility of scientists and engineers can sometimes create moral dilemmas. The interests of employers, private industry or public organisations alike may sometimes be at stake if a scientist or engineer speaks up in the public interest. These people often run into trouble, endangering their career or even their job. Codes of conduct published by professional associations are important to help people reflect on dilemmas (not primarily to prescribe a specific conduct) and to support individuals that speak up.[31] Figure 5.10 presents the code prepared by the Institute of Electrical and Electronics Engineers (IEEE).

Science and technology in the daily life of rich nations

In day-to-day life, citizens in rich countries have become completely dependent on technologies. However, they are hardly aware of it and this is how it should be. In general, if they become aware of technological dependence, something is wrong. For example, the non-functioning of an Internet connection is a minor nuisance. A major problem is a power cut. At home, people manage eventually with the help of the social network but, when a

28 D. Nelkin, *Controversy: Politics of Technical Decisions* (Beverly Hills, CA: Sage Publications, 1984).

29 P. Berg, D. Baltimore, H. Boyer, S. Cohen, R. Davis, D. Hogness, R. Roblin, J. Watson, S. Weissman and N. Zinder, 'Potential Biohazards of Recombinant DNA', *Science* 185 (1974): 303.

30 Cf. the European Science Shops Network; www.scienceshops.org, 9 November 2005.

31 Cf. the Online Ethics Centre for Engineering and Science; onlineethics.org/codes, 9 November 2005.

IEEE (Institute of Electrical and Electronics Engineers) Code of Ethics

We, the members of the IEEE, in recognition of the importance of our technologies in affecting the quality of life throughout the world, and in accepting a personal obligation to our profession, its members and the communities we serve, do hereby commit ourselves to the highest ethical and professional conduct and agree:

1. to accept responsibility in making engineering decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;
2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;
3. to be honest and realistic in stating claims or estimates based on available data;
4. to reject bribery in all its forms;
5. to improve the understanding of technology, its appropriate application, and potential consequences;
6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
8. to treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin;
9. to avoid injuring others, their property, reputation, or employment by false or malicious action;
10. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

Approved by the IEEE Board of Directors, August 1990

FIGURE 5.10 IEEE code of ethics

Source: www.ieee.org, 9 November 2005

blackout hits a whole city, the social organisation teeters on the brink of a total collapse. Such an event happened in New York in 1977:

> on the evening of July 13, 1977 lightning knocked out a major electrical transmission line [. . .] Within minutes of the electrical shutdown, looting broke out in widespread parts of the city, including the Upper West Side, East Harlem, and downtown Brooklyn. Police cars careened through dark streets, scattering crowds helping themselves to clothing, groceries, and furniture. In the South Bronx and Bushwick, fires burned out of control. By the time Consolidated Edison restored power the following evening, looters, rioters, and arsonists had caused an estimated three hundred million dollars in damages and the police had arrested more than three thousand people.[32]

Technology has intruded on everybody's life and most people seem perfectly happy about this. As we compare the lives of people in the rich world with those of people 500 years ago, technology makes them much more comfortable. People live longer and in a better condition, and there are far more of them. However, modern citizens still have concerns.

For example, we seem to accept the death toll from traffic accidents as a way of life. In the European Union alone, 42,500 people are killed every year and 3.5 million people are injured in traffic accidents.[33] After being a major political issue around 1970, the number of victims of traffic accidents fell considerable—partly through the introduction of safer technologies and partly by adapting the traffic system. Although traffic accidents are still an issue of serious concern, the victims are more or less considered to be the price that society accepts for its mobility.

Technologies are not just artefacts. In order to be able to use a technology, one has to know how to use the artefact, i.e. when to apply it, the proper way to activate it and the results it produces. We generally learn these things pretty fast, and are hardly aware that we learned them. But if this learning takes too much time or becomes too complicated, some people fail to achieve it (e.g. older people having trouble operating their computer or programming their video-recorder). This learning involves very minor issues, which become apparent only when somebody makes a mistake.

> When the railways introduced new doors in trains that closed automatically, sometimes people could be seen struggling with doors that did not close manually.

32 J.B. Freeman, *Working Class New York: Life and Labour Since World War II* (New York: New Press, 2000). See also: blackout.gmu.edu/events/tl1977.html, 9 November 2005.

33 European Transportation Safety Council (ETSC), *Intelligent Transportation Systems and Road Safety* (Brussels: ETSC, 1999).

In Barcelona, you can regularly see tourists struggling with the access gates to the metro, as they did not learn to feed the ticket into a slot at the left side of the gate instead of the right side.

Technological artefacts prescribe certain behaviour to us—otherwise they are pointless. These hidden prescriptions are called **scripts**. The clearest example of what happens if we do not know the 'scripts' can be seen in the 1970s comedy *Catweazle*.

> Catweazle was an 11th-century magician who ended up in our world by mistake. What made us laugh in the comedy was that Catweazle attributed his own scripts to the artefacts that he found. A welding shield was interpreted as a magic helmet, and so the script that Catweazle used was to wear it screaming various spells.[34]

There was another interesting feature of Catweazle. He interpreted the functions of modern artefacts within his magic framework. Thus, the telephone became a magic speaking bone. In the traditional magic framework, every object was besouled.

Modern citizens completely lost this framework of interpreting artefacts. Telephones are techno-scientific instruments that operate according to scientific laws, though few would be able to explain those laws. A magic or divine interpretation of the forces of nature is hardly attractive to the modern citizen. For example, storms are phenomena that can be foreseen and explained by meteorology. Lightning strikes are an electrical discharge of clouds, which can be explained by electromagnetic laws. Science removed the magic from the daily life. There are no longer divine blessings and punishments; there are just the laws of nature and bad luck.

The modern citizen is sceptical of stories of miracles such as reports of sacred wooden icons shedding a tear or the search for the monster supposed to lurk in Loch Ness in Scotland. Unidentified flying objects (UFOs) seem to be miracle stories that took the shape of our techno-scientific world-view. However, the recurrence of these stories seems to point towards new problems and feelings of unease resulting from the very success of science and technology:

- Who are we as humans? Is our life determined merely by the genes that combined in our conception and the strokes of good and bad luck afterwards? And, if so, what does it make us?
- Scientists in Edinburgh, Scotland, succeeded in cloning a mammal, Dolly the sheep, who was born on 24 February 1997.[35] In prin-

34 For some Catweazle clips, see: www.propaganda.com.au/catweazle/downloads.shtml, 25 January 2005.

35 www.sciencemuseum.org.uk/antenna/dolly/index.asp, 10 March 2006.

ciple, humans can be cloned too. Since 1978, babies can be conceived outside the mother's womb. Eggs can be fertilised in a test-tube and the fertilised eggs can be genetically screened. Where does this lead us? We are increasingly able to select our own descendants. Do we want only perfect babies? What does this imply for people that are less than perfect?

- In May 1997, IBM's Deep Blue Supercomputer played a fascinating game of chess with the reigning world champion Garry Kasparov, winning the sixth deciding match.[36] What does this do for us? Are humans just a stage in the evolution that will be surpassed by more intelligent designs?

It is beyond the scope of this book to answer these questions—if indeed they can be answered at all. What is clear is that modern science and technology affect us so deeply that fundamental questions arise for every human being.

Questions, discussion and exercises

1. The well-known Moore's Law (Figure 5.11) predicts that the number of transistors per square inch on integrated circuit boards will double every two years.
   a. Is this a proof of technological determinism, i.e. that this technology progresses regardless of changing social factors or could you also interpret it as an result of social construction?
   b. Search the internet for statements that support these two interpretations. Identify who is making these statements.
2. Check the history of your own university or institute.[37]
   a. Who founded it?
   b. What role was it intended to play in society? In what regard were its educational programmes new at the time of its founders?

36 See www.research.ibm.com/deepblue, 9 November 2005.

37 If not available, search the websites of one of the older engineering universities such as: Massachusetts Institute of Technology (MIT), libraries.mit.edu/archives/mithistory/index.html, 9 November 2005; Imperial College, London, www3.imperial.ac.uk/portal/page?_pageid=73,369046&_dad=portallive&_schema=PORTALLIVE, 17 March 2006; TU Delft, the Netherlands, www.tudelft.nl/index.cfm/site/Organisatie/pageid/66142E6B-8C71-EDEB-0D57799545A36F7D/index.cfm, 9 November 2005; RWTH Aachen, www.rwth-aachen.de/zentral/english_history.html, 9 November 2005; ETH Zurich, www.150jahre.ethz.ch/program/ethistory/index_EN, 9 November 2005.

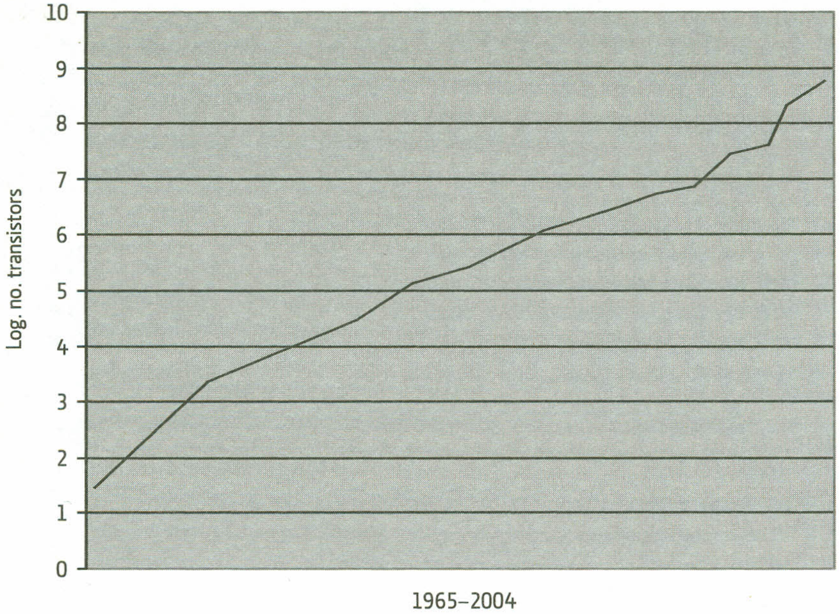


FIGURE 5.11 **Moore's Law (transistors per integrated circuit)**

Source: ftp://download.intel.com/pressroom/kits/events/moores_law_40th/MLTimeline.pdf, 9 November 2005

3. What is the control dilemma?
   a. Could you escape the control dilemma by making technologies flexible in regard to future changes or new knowledge?
   b. What would be the consequences of such a strategy for the development of new technologies?
   c. Discuss this with respect to the introduction of genetically modified crops or the development of nanoscale devices that could operate entirely on their own.