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The Use of Timber in the Twenty-first Century

1.1 Introduction

There is an increasing need to develop technologies in which renewable materials are used as direct replacements for nonrenewables. Our current rates of consumption of nonrenewables are high and in most cases increasing, but the reserves from which they are obtained are finite and exhaustible. Our present patterns of consumption are not sustainable in the long term. Although this problem appears to be unique to the 21st century, these concerns are not new. The idea that resource scarcity could act as a constraint upon economic development can be traced back to the writings of Thomas Malthus, who showed that expanding populations will outstrip their food supplies. The concepts that he discussed apply equally to all finite resources. In the event, advances in technology have tended to compensate for resource scarcity, but this process cannot continue indefinitely.

It is only comparatively recently that we have become acutely aware of the need to utilize resources in a sustainable manner. The concept of sustainability began to receive attention during the 1970s and was first formalized internationally in the World Conservation Strategy of 1980. The initial concepts were taken from the idea of *sustainable yield*, as applied in forestry and agriculture. This is defined as the amount of crop that can be harvested without compromising the capacity of future harvests to produce an equal crop. The level of consumption of a resource to support an activity should meet the needs of the present, whilst ensuring that sufficient resources are available to meet the needs of the future. The concepts of sustainability include social, economic and environmental factors. All three must be taken into account if the absolute sustainability of a process is to be determined.

As the study of the interactions between the environment and economic processes has developed, there has been increasing emphasis placed upon analyses of materials/energy

flows within economies. This has led to the development of the subject of biophysical economics, which views the economy in terms of flows of energy and materials within ecosystem processes. As a consequence, thermodynamic principles have become closely involved in the construction of biophysical economic models. The incorporation of environmental considerations into economics will be an important factor in improving the competitiveness of renewable materials.

1.2 Nonrenewables: a Finite and Exhaustible Resource

The consumption of nonrenewable materials tends to exhibit a classic relationship, which was first demonstrated by M. King Hubbert in an analysis of oil production from the 48 contiguous states of the USA. The shape of this 'Hubbert curve' is similar to, although not identical with, a normal distribution (Figure 1.1). With some variation, this pattern of production/consumption is exhibited for all nonrenewables. The finite life span of nonrenewable reserves has been commented upon by many workers in the area.

It is important to distinguish between the commonly used terms, resource, reserve base and reserve:

- A resource is the amount of material that is known to exist plus the quantity that is thought to exist.
- A reserve base is the amount of material in the resource that meets certain physical criteria for extraction.
- A reserve is the amount of material in a reserve base that can be economically extracted at the present time.

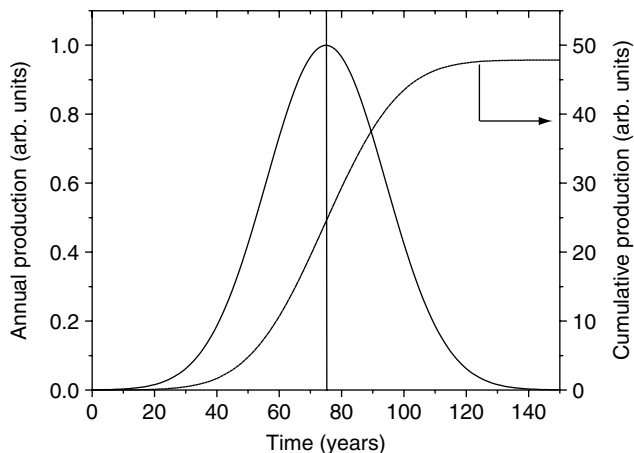


Figure 1.1 An example of a Hubbert curve, representing an idealized history of resource extraction. The amount of material extracted in a year is represented by the bell-shaped curve, whereas the cumulative amount of material extracted is given by the sigmoidal curve.

The extraction of nonrenewable materials follows a common pattern, in that the highest-quality reserves are the first to be extracted, and as these are worked out, progressively lower-quality reserves are then processed. As technology advances and the price of the commodity rises, the reserves increase.

However, although the level of reserves will rise as technology improves and prices increase, eventually there comes a point at which the effort (energy) expended in extracting the material is greater than the advantage gained by using that material. A good example would be the extraction of low-quality oil reserves, where a point is reached at which the energy expended in extracting the oil is greater than the energy obtained from the oil once it is extracted. Another example of this is illustrated by considering the amount of gold existing in seawater, with a total amount of 10 million tonnes being present in the world's oceans. However, this is at such a low concentration (10 parts per trillion) that extraction would be hopelessly uneconomic.

The US Geological Survey (USGS) produces annual mineral commodity summaries, from which it is possible to crudely estimate reserve lifetimes (Figure 1.2).

Calculations of this type are very approximate (obtained by dividing the current reserves by the annual production), but although the figures may be criticized in terms of absolute accuracy, the basic principle that the reserves will eventually be depleted cannot be denied.

The use of nonrenewable resources is characterized by linear mass/energy flows through economic systems. A resource is extracted, processed, utilized and ultimately discarded. Until recently, the final stage of this linear throughput has not been a factor when considering the economics of a process. Physical processes involving chemical transformations are subject to the laws of thermodynamics. An inevitable consequence associated with any chemical transformation is the unavoidable related increase in the entropy of the environment. This results in dissipation, the conversion of high-quality energy and materials into lower-quality forms (a decrease in organization at the atomic/

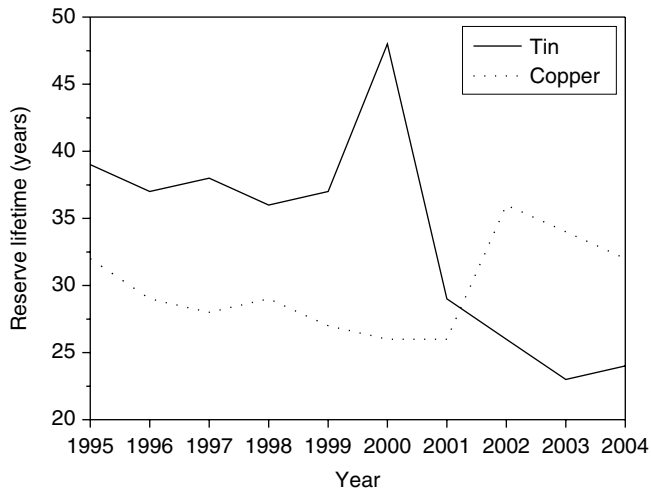


Figure 1.2 The reserve lifetimes of copper and zinc ores, estimated from the annual data supplied by the US Geological Survey.

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molecular level). A classic example would be the combustion of fossil fuels, where the high-grade heat (that which can do useful work) is emitted into the environment as low-grade heat, and the atoms in the fuel are lost into the environment as high-entropy gases (such as carbon dioxide).

Natural processes are distinguished from the material and energy throughputs of economic processes in two main ways:

- Cyclic materials flows, where the wastes from a metabolic process become the feedstocks for other metabolic processes.
- Assimilative rather than dissipative processes, where atoms are taken from a dissipated state and formed into organized structures.

Of course, natural systems do not operate outside of the laws of thermodynamics. The process of assimilating atoms to form organized structures requires energy, and this energy is derived (with a few exceptions) from the sun, via photosynthetic processes.

The challenge for mankind in the 21st century is to design our industrial processes so that they become integrated with natural metabolic processes. This is why the study of renewable materials is becoming so important.

1.3 Renewable Materials

Mankind has used (and hopefully will continue to use) renewable materials for millennia, but the idea of using renewable materials as industrial feedstocks began to be taken seriously in the 1930s in the USA (Geiser, 2001; Finlay, 2004). George Washington Carver was an early pioneer of this idea, who developed many industrial products derived from peanuts. The idea of using agricultural crops for industrial feedstocks was also promoted by William J. Hale, an organic chemist who published a book called *The Farm Chemurgic* in 1934. This was the start of the chemurgy movement. Hale argued that it was important from a strategic point of view for the USA not to rely upon foreign imports in order to support its domestic chemicals industry. This is an idea that seems just as pertinent now as it did then.

Hale worked with Wheeler McMillen, Thomas Edison, Irene DuPont and Henry Ford to promote the chemurgy principles. Thomas Edison was interested in using the wild flower goldenrod as a feedstock for rubber production. Henry Ford had a particular interest in producing industrial organic chemicals from soybeans. In 1938, Ford constructed the first of several industrial soy processing plants to make soy oil based enamels for car body paints, using the glycerol by-product in shock absorbers. He supported a great deal of research into crop-based products that could be used for producing car components.

The chemurgy movement grew rapidly during the time of the Great Depression, and the advent of the Second World War resulted in a huge amount of activity to derive as many products as possible from domestic sources, for strategic reasons. However, with the end of the war, the development of many new cheap products by the petrochemicals industry led to the rapid demise of the chemurgy movement.

With renewables, assuming that the biomass resource is obtained in a sustainable manner, there should be a constant supply of materials, although there is a finite limit to the amount of material that can be obtained. Figure 1.3 shows a classic growth curve

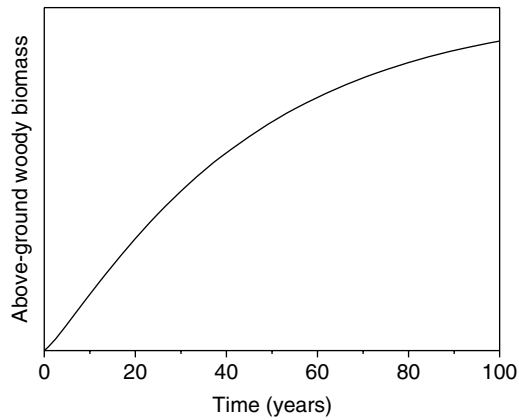


Figure 1.3 A growth curve showing the increase of biomass in forestry plantation over a 100-year period.

representing the amount of biomass stored in a crop, which is then available after harvesting to be utilized in products. It should also be noted that, theoretically, there is no downgrading of material quality for a renewable resource.

The biomass in (for example) a forest can be harvested and the sequestered carbon can either be used for energy production (with rapid return of the carbon to the atmosphere) or it can be stored for longer periods in timber products. The example given in Figure 1.4 shows a forest that is clear-felled after 100 years of growth.

The rate of growth of the trees slows as the forest reaches maturity and canopy closure occurs. In addition, the forest eventually establishes equilibrium with the environment, where the rate of carbon sequestration is exactly balanced by the loss of carbon dioxide to the atmosphere due to decay of dead trees and other biomass.

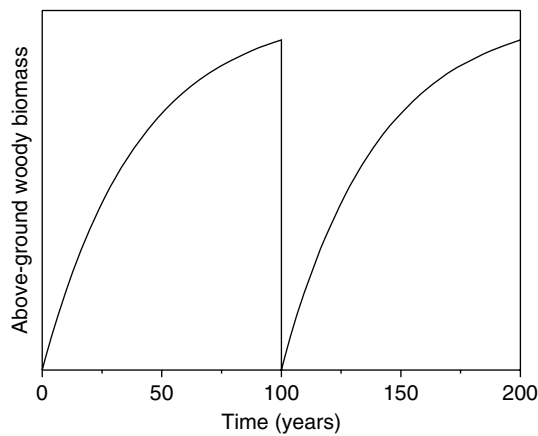


Figure 1.4 A forest plantation that is clear-felled after 100 years of growth, and subsequent regeneration over the following century.

The use of wood in long-life products, such as buildings, ensures that this sequestered carbon is held in a materials pool for a longer time. If the use of renewables is encouraged, then more carbon is stored in this manner. Eventually, of course, such systems will establish equilibrium with the environment, as the materials flow into the pool equals the materials flow out into the environment. The use of wood in this way intervenes in a natural cycle, so that wood use and ultimate disposal replaces the natural cycle of wood decay in the forest (Figure 1.5).

The use of forest resources as a feedstock for industrial uses is long established and is, in a sense, superior to the use of agricultural crops, since the supply can be guaranteed well into the future and can be obtained throughout the year, unlike seasonal crops. Although this book is concerned with one small aspect of timber utilization, it should be noted that forest resources can also be used to provide feedstocks for many industrial products, including chemicals.

Timber can be viewed as a classic renewable material. Trees absorb carbon dioxide and utilize water and sunlight to produce a material that can be used in construction, to produce paper or to provide chemical feedstocks, with the production of oxygen as a by-product. Furthermore, at the end of a product life cycle, the material constituents can be combusted, or composted to return the chemical constituents to the 'grand cycles'. In essence, timber use represents a classic example of a cyclic materials flow, mimicking the flows of materials through natural cycles. Provided that we manage our forests well and do not harvest beyond the capacity of the planet to provide timber, we have at our disposal an inexhaustible resource available in perpetuity.

The purpose of this chapter is to briefly consider the environmental credentials of timber utilization and the changes that are now affecting the way in which timber is used. It is not intended to comprehensively cover the topic, which would require an entire book, but it serves to outline the case for timber as a renewable material and to illustrate how environmental considerations are changing the way in which the material is being used. In particular, the use of wood preservatives, which have ensured that this renewable material has continued to remain competitive against nonrenewables, will be discussed. Finally, the importance of wood modification as an emerging technology will be briefly considered.

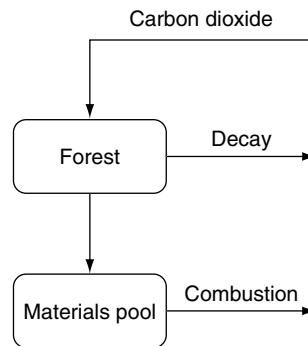


Figure 1.5 The use of wood products stores carbon in a materials pool, eventual disposal returning the sequestered carbon to the grand carbon cycle to provide for growth of new forest.

1.4 The Global Timber Resource

The industrial processing of timber has a long history and provides an excellent case study exemplifying how renewable materials can be processed, utilized and disposed of with minimal environmental impact. It is undeniable that unsustainable harvesting practices were used in the past, resulting in a generally poor perception of the industry by the public. It is also true that, in some parts of the world, harvesting of the timber resource continues to this day with scant regard paid to long-term issues of sustainability. However, there have been significant achievements in addressing the concerns that are often raised. The timber industry is long established, but continues to evolve to meet present and future demands. In response to criticisms, the forestry and timber-processing sector has introduced various certification schemes. The greatest interest in these schemes has been shown by importing countries, especially in Western Europe. According to the Food and Agriculture Organisation of the United Nations (FAO, 2001), the area of certified forests was 90 million ha in 2000, and continues to rise.

Globally, it is estimated that there is 3870 million ha of forests (30 % of the Earth's land area), of which 95 % is natural or semi-natural (Table 1.1). At the present time, in most developed countries, the forest area is increasing and this is likely to continue given the present rates of harvesting. However, in tropical parts of the world, the forest area continues to decline, giving rise to serious concerns. It is estimated that between 1990 and 2000, there was a loss of 9.4 million ha per annum of forest worldwide (an annual deforestation rate of 14.6 million ha and an increase in forest area of 5.2 million ha per year; Table 1.2). The only way to reverse this trend is to place sufficient economic value on forest resources, with incentives to encourage sustainable forest management.

Harvesting operations are moving away from virgin forests, and there is an increasing reliance upon plantations as a source of industrial timber, although the development of such plantations is relatively recent. According to the FAO (2001), half of all established plantations are less than 20 years old. It is predicted that future increases in wood demand will be met largely from plantations.

Table 1.1 Forest area by region (FAO, 2001)

Region	Land area (million ha)	Total forests (natural and plantation)			Natural forest (million ha)	Plantation forest (million ha)
		Area (million ha)	% of land area	% of global forests		
Africa	2 978	650	22	17	642	8
Asia	3 085	548	18	14	432	116
Europe	2 260	1 039	46	27	1 007	32
North and Central America	2 137	549	26	14	532	18
Oceania	849	198	23	5	194	3
South America	1 755	886	51	23	875	10
World total	13 064	3 869	30	100	3 682	187

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Table 1.2 The annual gross and net change (in million ha) in forest area by region, 1990–2000 (FAO, 2001)

Domain	Deforestation	Increase in forest area	Net change in forest area
Tropics	-14.2	+1.9	-12.3
Nontropics	-0.4	+3.3	+2.9
World	-14.6	+5.2	-9.4

Global production of roundwood was 3335 million m³ in 1999 (3352 million m³ in 2000), about 50 % of which was as fuel wood, of which 90 % was consumed in developing countries. Industrial roundwood production (1550 million m³ in 1999) was dominated by developed countries (79 % of total annual production). This trend will change, in particular with the emergence of China as a major economic force.

1.4.1 Timber and the Carbon Cycle

In recent years, there has been increasing concern over the build-up of greenhouse gases in the atmosphere, particularly CO₂, as a cause of global warming. A number of reports have been issued by the Intergovernmental Panel on Climate Change (IPCC), outlining the scientific basis behind this concern. It is well established that the carbon dioxide derived from anthropogenic emissions arising from the burning of fossil fuels for energy is a major greenhouse gas. Deforestation and land-use change also play a significant role in contributing to the increase in levels of atmospheric carbon dioxide. It is estimated that emissions of CO₂ due to the burning of fossil fuels amount to some 6 gigatonnes (Gt) of carbon per annum, whilst deforestation contributes an additional 2Gt. It has been calculated that the total amount of carbon emitted up to the year 2000 due to fossil fuel use, plus that due to land-use change, is of the order of 420Gt of carbon. Projections based upon the work of the IPCC estimate that the amount of carbon that will be emitted in the 21st century range from 690 to 2090Gt of carbon (Cannell, 2003). However, biological systems also have the capacity to reverse or ameliorate this trend, because the atmospheric carbon can be sequestered in sinks, such as expanding forests. It is estimated that the world's forests presently contain over 4×10^{12} tonnes of biomass (Table 1.3).

Table 1.3 The distribution of above-ground woody biomass by region (FAO, 2001)

Region	Biomass (million tonnes)	%
Africa	70 916	16.8
Asia	45 036	10.7
Europe	61 070	14.5
North and Central America	51 895	12.3
Oceania	12 350	2.9
South America	179 497	42.7
World total	421 214	

The process of tree growth utilizes atmospheric carbon in the production of wood biomass. Furthermore, this sequestered carbon can continue to be held in products that are manufactured from wood. Although much research has been done in investigating forests as actual or potential carbon sinks, there has been rather less work looking at the implications of the use of wood products as a medium-term carbon store.

Although forest biomass can be used as a sink for anthropogenic CO₂, as the forest matures, the carbon inventory reaches a plateau as the forest establishes equilibrium. Thus, in order to ensure continued sequestration of atmospheric carbon, it is necessary to harvest the biomass (and replant, or allow for natural regeneration) and utilize this material in long-life products, thereby removing the carbon for longer periods in materials pools. Providing markets for timber ensures the survival of the forestry industry and provides an incentive for further planting. In the EU at present, only 7% of carbon emissions are offset by growth of wood biomass (Liski *et al.*, 2000). Large-scale afforestation programmes could be used as a means of sequestering much larger amounts of CO₂ than at present, if the political will was present (Booth and Elliott, 1993). If significant afforestation was to be implemented immediately, then an extra 52–104 Gt of carbon could be sequestered in trees over the next 50 years (Cannell, 2003). However, the implementation of forestry programmes to offset anthropogenic carbon emissions can only be viewed as part of an overall strategy to reduce global warming. For example, if *all* of the agricultural land of the EU15 was to be used for forestry, then the amount of carbon sequestered would represent only 20–55% of the current EU15 emissions (Cannell, 2003). It will clearly not be possible to achieve this, and other measures must also be implemented to reduce CO₂ emissions.

The growth of woody biomass in one year's 'annual increment' represents the quantity of material that can be harvested without affecting the productive capacity of the forest in subsequent years. The gross annual increment (GAI) is the yearly increase in woody biomass, whereas the net annual increment (NAI) is the GAI adjusted for natural losses such as fire, insect damage and so on. The NAI is often referred to as the 'allowable cut'. In boreal and temperate zones, the removal of woody biomass is lower than the NAI, and thus these forests are presently acting as net sinks for carbon dioxide (Figure 1.6). If all of the NAI was harvested, then the forests would no longer act as sinks for CO₂, but would be in balance with the atmosphere.

The material that is harvested can be utilized in products, and when they are disposed of, the sequestered carbon is returned to the atmosphere. This gives rise to the often-quoted property of timber as being 'carbon neutral'. However, this is erroneous, in that harvesting, transport and conversion of timber all result in net carbon emissions, which must be taken into account in carbon balances. But if the timber is used to substitute for products that have higher carbon emissions, then real gains are achieved. The arguments for the utilization of timber are complex and outside the scope of this book, but the following conclusions can be drawn:

- If the forest resource is properly managed, then timber can be harvested indefinitely.
- The use of timber in products represents a means by which atmospheric carbon can be stored in materials pools.
- Extending the life of timber products will result in carbon being stored in a materials pool for longer periods.
- Ultimate disposal of timber products will return the sequestered carbon to the atmosphere, where it is available for continued production of timber.

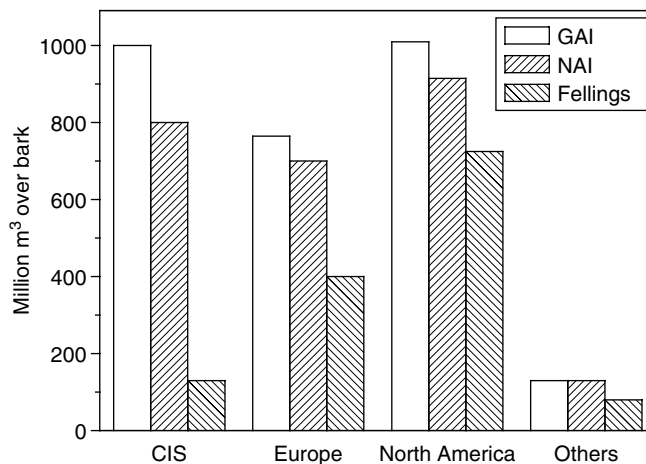


Figure 1.6 The net annual increment and fellings for temperate and boreal zone forested countries.

It is important to emphasize that forestry is a long-term industry. Decisions taken now concerning the way in which we manage our forests will have an effect way into the future, perhaps as much as a century later.

1.5 Timber Production

Wood has been used by mankind for millennia because of its excellent material properties. Although the use of timber in some markets has decreased, the consumption of timber overall continues to rise. Projections have been made until the middle of the 21st century that in most cases show a rise in demand for timber (in all but low economic growth models) and an increase in production (Figure 1.7) (Brooks *et al.*, 1996). There is, however, concern that the supply of timber for industrial purposes may not be able to match demand. For example, Bowyer *et al.* (2003), note that there will be a shortfall in the amount of forest area providing industrial timber by the year 2100, due to the rise in human population during this time (Table 1.4).

This requires the urgent development of new technologies to ensure the more efficient use of the resource by, for example, extending the life of timber-based products.

Increasing quantities of timber are being sourced from managed plantation forests, which are now being established at a rate of over 3 million ha per year. These plantation forests have often been developed to utilize fast grown species (such as *Pinus* and *Eucalyptus*), where yield rather than timber quality is the primary consideration for species choice and management methods. Active management of plantation forests utilizes thinning regimes to maximize yield, sometimes combined with fertilization of the soil to encourage growth. Plantation forests in the temperate zones invariably utilize softwood species chosen for ease of conversion and management.

Fast grown softwood from plantation sources is generally characterized by a high proportion of juvenile wood and often poorly developed heartwood. A fast rate of growth results in wide growth rings, producing low-density timber that exhibits inferior mechanical

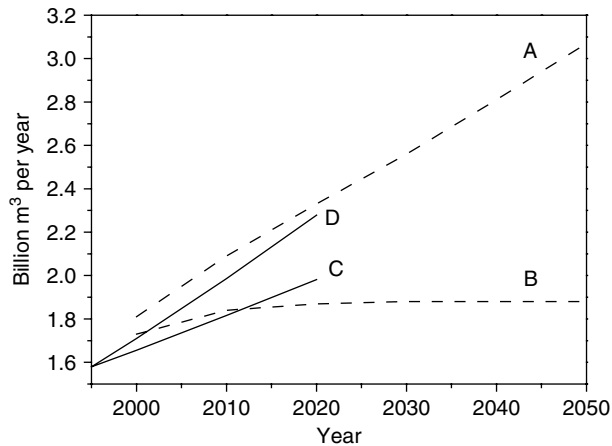


Figure 1.7 Predictions of growth of timber production and consumption globally until 2050 (Brooks et al., 1996). (A: high demand, B: low demand, C: low production, D: high production).

Table 1.4 A comparison of global annual per capita wood consumption for the years 2000 and 2100 (Bowyer et al., 2003)

Net annual forest growth	1.5 m ³ ha ⁻¹
Annual per capita wood consumption	0.5 m ³
Forest area required per capita to support consumption	0.4 ha
Forest area available per capita, 2000	0.6 ha
Forest area available per capita, 2100	0.3 ha

properties, when compared with timber sourced from virgin forests. There is also evidence to show that the durability of plantation-grown timber is often inferior to that sourced from natural-growth forests. All of the above factors result in an inferior product compared with the material obtained from virgin forests, requiring some means of upgrading the timber to achieve comparable properties. The harvested timber from semi-natural forests may often be of higher quality, but reduced rates of production place more severe constraints upon the quantity of material that can be extracted in a given time period.

Changes in the quality of feedstock have resulted in the introduction of new timber processing technologies, in particular the production of reconstituted timber and engineered wood products, which do not rely upon the availability of large-diameter logs, which are now in increasingly short supply. The declining quality of timber is a powerful impetus to the development of technologies to upgrade wood quality.

1.6 Wood Preservation

Although wood is a perishable material, this can be seen as an advantage, in that wood can be disposed of into the environment at the end of its useful life, where its molecular constituents are broken down by natural processes and assimilated into nutrient cycles.

However, it is obviously not desirable that this process takes place when wood is used in service situations.

In the past, undesirable properties such as susceptibility to biodegradation were overcome by the use of durable hardwood (in the main) species, particularly tropical hardwoods. This has contributed to tropical deforestation, although factors other than harvesting for industrial timber have had a greater effect. Nonetheless, extraction of target trees from virgin forest leads to a substantial environmental impact and there is a strong tendency for settlement to follow logging roads, with practices such as slash and burn of the forest occurring. This has led to substantial public disquiet regarding tropical forest operations, and this poor public perception has gradually encompassed virtually all forestry operations. Furthermore, the quality and quantity of tropical wood has declined as the resource becomes scarcer and more expensive to extract.

As the availability of naturally durable species has declined, the industry has turned to softwoods, and increasingly to softwoods from managed forests or plantations. In order to achieve acceptable longevity under service conditions, it has been necessary to use preservatives to prevent biological attack. Such preservatives have tended to rely upon broad-spectrum biocidal activity and have become very common, particularly for exterior applications.

The beginning of the modern timber preservation industry can be traced back to the late 1830s, when Bethell developed a method for the pressure impregnation of timber. This was used for the treatment of sleepers and poles for the rapidly expanding railway industry, using creosote and tar oils. The early part of the 20th century saw the development of water-based systems employing arsenates, chromates, fluorides and nitrophenols. In 1933, an Indian government research officer (Dr Sonti Kamesan) developed the first copper–chrome–arsenic (CCA) wood preservative. This proved to be an excellent wood preservative that was used in increasing amounts throughout most of the 20th century.

Although CCA is an exceedingly effective preservative in service, attention has increasingly been focused on the fate of CCA when the treated timber products are disposed of. This has led to concerns especially regarding the ultimate release of arsenic and chromium into the biosphere.

Concerns have also been raised regarding the use of chromium and arsenic in preservatives where there is a high probability of human exposure to the treated products. In this context, it should be noted that, in a study of the consequences of the use of CCA-treated wood in playgrounds, it was concluded that children would have to ingest 10–30 kg of soil in the immediate vicinity of the treated timber on one occasion for it to pose a hazard (Henningsson and Carlsson, 1984). Nonetheless, legislative bodies have adopted a precautionary approach regarding the use of CCA-treated wood where a high probability of human contact is expected.

As a consequence of these concerns, many countries have now either banned the use of CCA outright or have severely limited its use to specific products or market sectors. Even in the latter case, there can be no doubt that an outright ban will follow in time.

Analyses of the quantities of various treated timbers used in various countries have been performed and some examples are given herein to illustrate the scale involved. In 1990, 1 967 600 m³ of preservative-treated wood and 327 000 m³ of anti-sapstain treated wood was used in the UK (Jermer, 1990). Of this total, 68 900 m³ was composed of poles and sleepers, sawn/other wood products comprised 1 484 600 m³ (75 %) and fencing

posts accounted for $414\,100\text{ m}^3$ (21.5%). Within the 15 member states of the European Union prior to enlargement, approximately $18 \times 10^6\text{ m}^3$ of timber was preservative treated, with $10.3 \times 10^6\text{ m}^3$ of this being for construction timbers. In 1991, global annual consumption of CCA was estimated to be 118 thousand tonnes, with Europe consuming something of the order of 39 000 tonnes. Japan used 96 500 tonnes of CCA in 1980, but this had declined to 2 thousand tonnes by 1989. Although the constituents of CCA are fixed in the wood during the lifetime of the product, they cannot be regarded as permanently immobilized, since the treated wood must ultimately be disposed of.

This treated wood will inevitably appear as waste in the future and strategies for disposal will have to be developed. At the present time, procedures are being developed to collect preservative-treated timber, incinerate the material, and recover the flue-stack emissions and ash to prevent dispersal into the environment. A significant concern with the use of incineration is the high volatility of arsenic (Dobbs and Grant, 1978). There have been suggestions that the recovered metals could be reused in preservative treatments, resulting in a cyclic flow of the metals used for wood preservation. Whilst such recovery schemes are highly desirable and should be developed, there is no denying that 100% recovery of the metals derived from preservatives is not achievable, even theoretically, and there will inevitably be dissipation into the biosphere. Even assuming 90% recovery, there is an inevitable dissipation of 10% of the metals into the biosphere with each recovery cycle. It can be readily shown that after only seven recovery cycles, just over 50% of the material has been dissipated into the environment (Figure 1.8).

Whether the reuse of the metals obtained from incineration as a preservative, or some form of permanent immobilization is preferable requires careful thought. Low-temperature pyrolysis has been suggested as an alternative to incineration, since this would be expected to lead to lower losses of metals (Helsen *et al.*, 1998).

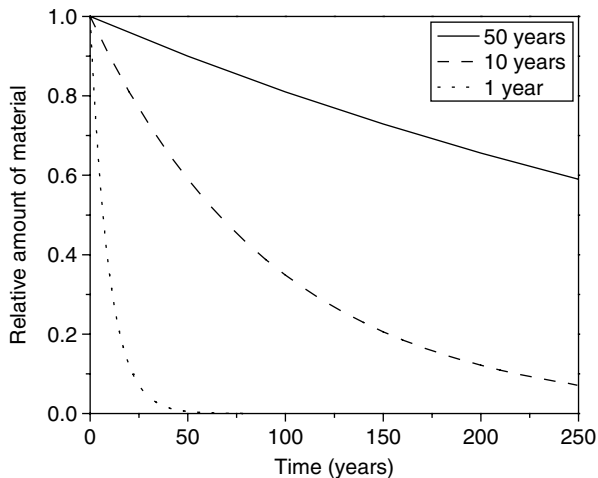


Figure 1.8 The loss of material into the environment as a result of recycling processes, assuming a recycling efficiency of 90% and product lifetimes of 1 year, 10 years and 50 years.

Alternative strategies have also been proposed, in which the metal components are removed from the wood prior to incineration. These include extraction using phosphoric acid (Kazi and Cooper, 2002), ethylenediaminetetracetic acid (Nami Kartal, 2003) or oxalic acid combined with bacterial culture (Clausen, 2004a,b), and electro dialysis (Mateus *et al.*, 2002).

Although both copper and, to a greater extent, chromium (Cox and Richardson, 1978; Richardson and Cox, 1985) have associated environmental impacts, particular concerns have been expressed regarding the use of arsenic.

1.6.1 Arsenic

Arsenic occurs primarily in sulphide minerals associated with copper ores, and to a lesser extent with zinc, lead and gold ores. Arsenic is produced as a by-product of the smelting of these metals. Primary arsenic production has now ceased in the USA and Europe, and most arsenic is now imported from China and Mexico. The volatility of arsenic represents a significant concern, and there is at present no known natural mechanism by which arsenic is immobilized in the environment. Anthropogenic activities account for an input of some 19 000 tonnes into the atmosphere, compared with 12 000 tonnes from natural processes, such as volcanism and forest fires (Ayres and Ayres, 1996).

Until the mid-1970s, the most significant industrial use for arsenic was as general agricultural pesticides, and as desiccants in the cotton production process. According to the US Bureau of Mines, the use of arsenic for agricultural purposes was in the range of 15 000–20 000 tonnes per annum between 1963 and 1973. As agricultural use declined, there was an increase in the use of arsenic for wood preservation, with over 25 000 tonnes of arsenic being used for this purpose in 1998. According to the USGS, it has been estimated that by 2010 the amount of arsenic in discarded treated wood will be of the order of 14 500 tonnes in the USA.

Arsenic is also used in small quantities in the manufacture of lead–acid batteries (which are recycled), in the production of a few nonferrous alloys and in the electronics industry. It has been suggested that rather than importing primary arsenic for industrial uses, this could be recovered from wood waste, although the amounts required are only of the order of one to two thousand tonnes per year in Europe, and similar amounts in the USA (Lindroos, 2002).

1.7 Preservative-treated Wood and Legislation

Concerns about the disposal of preservative-treated wood, as well as perhaps less well founded concerns regarding the safety of preservative-treated wood in service, have resulted in countries introducing legislation to phase out certain classes of preservatives. At present, toxic metal containing preservatives are being banned, or restrictions placed upon their use, with the trend in wood preservation being towards the use of low-toxicity metals (e.g. copper and zinc) and organic nonchlorine-containing biocides. Legislation is also moving towards the registration of wood preservative chemicals, with certain requirements being placed upon determining the environmental impact of using these chemicals. Such restrictions are inevitably going to lead towards increased costs in the

development of new biocides, and it is most unlikely that any new biocides will be developed specifically for wood preservation.

In February 2002, the US Environmental Protection Agency announced a voluntary decision by the lumber industry of the United States to replace the sale to consumers of CCA-treated wood with alternative preservative systems by the end of 2003. This voluntary ban affected all residential uses of CCA-treated wood, including decking, picnic equipment, playground equipment, residential fencing and so on. In the EC, Commission Directive 2003/02 (6 January 2003) was published, concerned with restrictions on the use and marketing of arsenic. According to this directive, CCA-treated wood will not be allowed for certain end-uses (Table 1.5). As of 30 June 2004, the net effect of this directive is to severely restrict the use of CCA-treated wood in situations in which there is the potential of human contact. These restrictions apply to imported treated wood and to waste wood containing preservatives. From 2007/8, CCA will require authorization according to the Biocidal Products Directive (BPD).

Similarly, legislation has been, or will be, introduced to deal with the disposal of treated wood waste at the end of a product lifetime. No longer will it be acceptable to dispose of treated wood waste by dumping in landfill. Proper disposal will require the incineration of treated wood waste in appropriate facilities that have the necessary equipment to prevent stack emissions of toxic compounds. This requires expensive investment to build plant that can meet the relevant environmental requirements. Such methods probably represent the best option for the permanent removal of these potential pollutants. The ash generated in these plants may contain high concentrations of arsenic, which will then have to be disposed of as hazardous waste.

The recycling of wood waste is also increasingly being used, where timber products at the end of life are usually reduced by chipping, or fibre production, and the resultant material is then reused in reconstituted wood products. Strict monitoring and control are required in order to ensure that inappropriately treated waste is not included in the feed-stock stream for recycling wood. The use of recycled wood in reconstituted products is rising rapidly; for example, in the UK, the panel products industry used 400 000 tonnes of recycled wood in 1999, and this had risen to 932 000 tonnes by 2002 (UK Forestry Commission data 2003).

Table 1.5 Allowed and unacceptable uses of CCA-treated wood according to European Directive 2003/02/EC

Allowed uses	Unacceptable uses
Timber used structurally in public, agricultural, office or industrial buildings (no human contact)	Residential or domestic constructions (all uses)
Bridges and bridgework	Any application where there is a likelihood of repeated dermal contact
Constructional timber in freshwater areas	Marine water installations
Noise barriers, highway safety fencing, earth-retaining structures, avalanche control, livestock fence posts	Agricultural uses, other than fencing or structural uses
Utility poles (electric power transmission, telecommunications)	Applications where the treated wood may come into contact with products intended for human or animal consumption

All of the above environmental concerns are leading to restrictions being placed upon the use and composition of preservatives used to treat timber. Preservative systems of the future will therefore be selected not simply on the basis of criteria such as efficacy and cost, but also environmental impact, both during service and at the end of product lifetime. This will inevitably have economic implications.

1.8 Competition from Nonrenewable Materials

Timber continues to be used in huge quantities in the built environment. However, for some applications there has been significant competition from nonrenewable materials. Concrete, cement, brick, stone, ferrous and nonferrous metals, and various polymeric materials have all been used in place of timber and in some cases have completely replaced timber for some applications. The almost complete loss of the window and door markets to competitors such as unplasticized polyvinyl chloride (uPVC) has been a serious blow to wood processors in some countries. This change has been brought about mainly due to public demand, with wooden products being perceived as having high maintenance requirements and poor performance in service. Aggressive marketing has also attempted to portray timber as an environmentally unfriendly material, with the use of nonrenewables being a better option, since this leaves the forests intact. This publicity has also been backed up by life cycle analysis (LCA) studies purporting to indicate the superior environmental credentials of certain nonrenewables. The timber sector was slow to respond to this threat and has only recently begun to reclaim lost markets. In some cases, the appropriate response has been to design better products, or to use more sophisticated manufacturing methods. However, it is much more complex to counter the negative environmental arguments.

The whole area of LCA is very complicated and it is not possible to do sufficient justice to the topic within the space limitations of this volume. However, contributions to the apparent negative environmental impacts of timber could include unrealistically high maintenance requirements (e.g. regular applications of paint or varnish, and regular inspection), the use of preservatives and the assumption of a relatively short product lifetime due to deterioration in service. Favourable LCAs for a material such as uPVC can be obtained by assuming that all material at the end of a product life will be recycled (thus ignoring ultimate disposal), assuming that the product life is equal to the life of the material, or assuming low maintenance requirements when compared with timber.

The replacement of timber products by nonrenewable materials is an unfortunate development, since it has been repeatedly shown that the use of timber does have associated environmental benefits compared with the use of nonrenewables (e.g. Marcea and Lau, 1992; Hillier and Murphy, 2000; Bowyer *et al.*, 2003; Lippke *et al.*, 2004). Timber has a lower embodied energy content (and hence a more favourable carbon emission profile) compared to most other building materials and can provide other benefits, such as improved thermal properties. It and the products made from it (in common with other renewable materials) can be used as a repository for atmospheric carbon dioxide. Wood is derived from a renewable resource, albeit potentially an exhaustible one unless it is managed correctly. Disposal of wood can be readily achieved with little environmental impact (subject to how the wood has been treated prior to disposal).

Unfortunately, one consequence of the ever more stringent controls upon the use of preservatives and upon preservative-treated wood will be the rejection of wood as a construction material.

1.8.1 Polyvinyl Chloride

The estimated annual production of PVC for all applications is around 22 million tonnes (Jakslund *et al.*, 2000). In many ways, uPVC is an excellent material. It is very stable and exhibits good durability, making it ideal for use in long-lived low-maintenance applications (such as underwater drainage). However, it should be noted that uPVC usage carries with it significant environmental impacts. Although PVC production waste is recycled mechanically, most of the post-consumer waste is not, with much of it being disposed to landfill at present. PVC exhibits a degree of thermal and UV instability, requiring the use of metal-containing compounds, such as cadmium soaps, as stabilizers. Degradation of uPVC products in exterior service has resulted in paint manufacturers producing products specifically for application to uPVC.

Production of elemental chlorine for the synthesis of vinyl chloride monomer (the biggest single use of chlorine worldwide) can have significant environmental impacts, particularly if a mercury cell is used for chlorine production. Ultimate disposal of uPVC does not appear to have been seriously addressed until now, with some analyses even assuming 100 % recycling of the material into new products. Even if this was technically (or even thermodynamically) possible, it still does not address the issue of *ultimate* fate. With present technologies, this can only be dissipation into the environment, landfill or incineration. There is research under way investigating alternative means of recycling PVC waste, other than mechanical grinding, although the costs of such processes are not yet known (Jakslund *et al.*, 2000).

1.9 The Need for Wood Modification

Due to environmental concerns regarding the use of certain classes of preservatives, there has recently been a renewed interest in wood modification. Wood modification represents a process that is used to improve the material properties of wood, but produces a material that be disposed of at the end of a product life cycle without presenting an environmental hazard any greater than that associated with the disposal of unmodified wood. Although wood modification has been the subject of a great deal of study at an academic level for over 50 years, it is only comparatively recently that there has been significant commercial development.

1.10 Conclusions

Although timber production and utilization can result in substantial environmental benefits compared with materials extracted from nonrenewable sources, timber utilization and forestry have become associated with negative environmental impacts. Tropical deforestation

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continues to be a cause of concern, although there are many factors associated with this other than timber production. The demand for timber will continue to rise, leading to concerns of a timber shortage by the end of the 21st century. In the future, increasing quantities of timber will be sourced from managed forests and there will be an associated reduction in timber quality in some cases. Environmental concerns have led to legislation that has resulted in significant reductions in the quantities of timber treated with conventional preservatives (especially CCA). These trends will continue in the future, with the cost of preservative-treated timber rising. There has been a significant increase in the use of materials obtained from nonrenewable sources as substitutes for timber in some markets. These significant changes in the timber sector have resulted in a significant increase in interest in wood modification as a means of improving the properties of the material.