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LONG-TERM PROSPECTS FOR INDUSTRIAL MATERIALS

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ABSTRACT: The paper gives an overview on the future adequacy of industrial materials. The availability of materials is determined by reserves, exploitation and most importantly by technological advance. Material scarcities have been overcome by scientific and technological advances. The price mechanism ensures the appropriate response.

KEY WORDS: Raw materials, Resource economics

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INTRODUCTION

The year 2017 will mark the 100th anniversary of the independence of Finland. What will be the shape of the world in 2017? The scope for speculation about the future is very wide indeed, embracing - among many other imponderables - the vexed problem of global warming and allied environmental phenomena which, if the more pessimistically minded scientists may prove right, could change the face of our planet.

Since independence in 1917, Finland has developed from a chiefly agricultural into an industrial country where the service sector is gaining increasing importance. Her industry cannot function without the adequate supply of base materials (and to a lesser extent the agricultural and service sectors are in the same position). This is why this paper concentrates on the future adequacy of industrial materials.

There is probably no industrial material that, in one form or another, is not used by some sector of the Finnish economy. Yet, the country's natural endowment, apart from forestry, is poor. For covering her needs Finland relies on international trade - in fact on the world's resources. It follows that our forward look must take a wide perspective, covering all industrial materials on a worldwide horizon.

Looking about a quarter of a century ahead cannot be free of uncertainties. Churchill's view becomes very relevant, who said: 'It is always wise to look ahead but difficult to look further than you can see'. The sight is blurred indeed. Nevertheless, we agree with the leader of one of the world's largest corporations who said that 'it is a fool who acts on quantified long-term forecasts because they usually prove wrong; there is only one behaviour that is even more foolish: not to think about the future at all'.

In this paper we avoid quantified forecasts for the year 2017; we will discuss scenarios based on facts stemming from the knowledge of the present and the past.

Our intention is to cover here all industrial materials, including even water, with the exclusion of energy. We recognise the utmost importance of energy supplies but just because of their vital significance - and somewhat different nature - they deserve separate treatment. There are other topics too which may require studious discussion if we want to sketch a possible picture of the world in 2017 - such as population, land use and many others; their omission in no way means belittling their importance. Although food constitutes the raw material of one or two branches of industry we are not dealing with the outlook for future food production and the problems of food-producing agriculture. Finally: whilst environmental questions are related to almost any aspect of the supply of industrial materials in the future, these issues are touched upon only to the extent it is necessary; a fuller discussion of environmental issues is not aimed at.

Industrial materials are usually classified, rather crudely, into two large groups: the non-renewable and the renewable materials. We are devoting more attention - for obvious reasons - to the first group though not neglecting the second.

Non-renewable materials: minerals and metals

Cryolite is an essential ingredient of aluminium production, used as a flux in the electrolytic process. The world's largest cryolite deposit was in Greenland; it was almost totally depleted in the early 1960s. It was not a sudden and unexpected disappearance: rapidly rising demand for aluminium, and hence for cryolite, outstripped available supply considerably earlier. This resulted in the search for its replacement, eventually producing synthetic cryolite (Tilton, 1977).

This example, taken from the Nordic sphere, is meant to illustrate the three phenomena that determine the availability of materials for industrial use: reserves (in other words: the worldwide stock), exploitation (the continuous production that reduces non-renewable stocks) and technological progress. In any future scenario attention has to be paid to all three; the most important among them - particularly when looking far ahead in time - is scientific progress and consequent technological advance or change because it is all-pervasive. Its impact affects every single phase from the exploration and search for the material to the use of the final product by the end-user.

The case of cryolite is not unique. In the two centuries since the start of the industrial revolution - and much before - demand for industrial materials has been growing rapidly and continuously; mankind's needs could not have been satisfied without the even more rapid advance in science and technology (Rosenberg, 1973). This is why we will start this study with various aspects of technology.

Technological progress is difficult to foresee; this is one of the reasons why some earlier forward-looking exercises misjudged the future.

Some earlier views

Our aim now is to look about a quarter-century ahead; it is useful before doing so to take a backward look at a crudely comparable period, particularly because that was quite eventful in the area of industrial materials. At the beginning of the past quarter-century announcements of the members of the 'Club of Rome' directed attention to the finite state of the world's resources; these received strong support by two publications (Forrester, 1971 and Meadows, 1972) painting the world's future materials supply with dark colours indeed. In the course of the subsequent lively debate (e.g. Beckerman 1974, Cole 1973, World Bank 1972) more optimistic views were expressed; so far these latter proved right. Although the 1972-3 explosion of commodity prices and the first oil shock in 1973 seemed at the time to vindicate the doomwatching views, both turned out to be temporary, normality had soon been re-established (although in the case of oil it took quite a long time).

Classical theorists expressed considerable anxiety but history shows that so far the Malthusian trap has been avoided in the area of materials (and in that of food too) and there has been no trace of the Ricardian stagnation due to land shortage or of the Marxian demand shortage (Pavill, 1973). The scarcity of British coal feared by Jevons (1865) - and the same feeling expressed by Gladstone in his 1863 budget speech - did not materialise. In the second half of the 19th century there was a lively conservation movement in the USA; its champions believed that American resources would soon be exhausted (Barnet & Morse, 1963). Had Pehrson's (1945) review been correct, the Americans would by about 1980 have totally exhausted their reserves of half of the 41 commodities examined; in fact, US reserves are now estimated in most cases higher than in the 1940s.

Nor were resource needs more accurately foreseen. The best example is the Paley Report (1952) which was carefully analyzed twenty years later by Cooper (1975). According his post-mortem the consumption of most minerals was overestimated in the Paley Report although national output was growing a good deal faster than foreseen and this falling material intensity was largely due to 'technical and managerial changes'. Thus, technological changes influenced both the supply and the demand sides; as a result the fundamental scarcity foreseen at the time by many scholars was avoided. This, however, does not mean that there were no shortages of materials or scarcities but these were either of relatively short duration or could be bridged otherwise.

Material scarcities and shortages - a random walk in history

As soon as a material is in short-supply its price rises. Prices can therefore be taken as reliable signals of the degree of availability. The commodity price indicator produced by The Economist (London), starting in 1845, covers almost 150 years, most of the modern industrial period. This index includes all major industrial materials (and food) but excludes coal and oil. Its long curve indicates four outstanding peaks, reflecting major events in history. The first was in 1864; it was the outcome of the American Civil War which lead to the 'cotton famine'.[1)] The second, around 1920, was the culmination of a long period of rising prices which started with the outbreak of the 1914-8 war and ended in shortages after the war. The next peak came in 1951 under the impact of the Korean War. The last peak was in 1972/3, towards the end of the postwar long and rapid increase of industrial activity when demand temporarily outstripped supply. After each of these peaks prices fell, often heavily, supply and demand regained some kind of equilibrium and the market situation returned to normal. The price-indicated shortages were temporary and the speedy normalisation pointed clearly to the absence of any fundamental long-term scarcity. However, behind this generalisation which concerns the overall situation of the aggregate of all commodities there have been cases of serious shortages and fundamental scarcities of individual commodities during this nearly 150 years period and also earlier.

In what follows some of them will be briefly mentioned. The purpose of this sketchy survey is to demonstrate that mankind faced serious material scarcities in the course of history and - at least so far - in every single case it was scientific and technological advance that provided the solution.

Natural shortages occurred very early in human history: in the 5th century BC the growing shortage of timber was noted in Athens (French, 1964). The same was a serious worry of Elizabethan England in the 16th century: timber prices, especially those of fuelwood, rose three times as fast as the general price level and the use of fuelwood for certain purposes was limited by law (Rosenberg 1973). Although this stimulated the search for other fuels (Hill, 1969) and helped the ascent of coal, the replacement of timber for industrial and fuel use took a long time with the result that by the middle of the 19th century "the forests had all gone, save a patch or two" (Trevelyan 1964).

Wood shortage affected the supply of alkalis (potash and soda, prepared from potassium and sodium carbonates) used in earlier times in many applications, from textiles to gunpowder, Potash was obtained from wood ash and required enormous quantities (Landes, 1969, mentions a proportion of 1:600), soda from a special plant grown mainly in Spain. Leblanc worked out a method in 1784 of obtaining soda from common salt and when the French were cut off from Spain in the Peninsular War they began the manufacture of soda by the Leblanc process in 1808 (Rosenberg 1976).

1) The Economist indicator is a chain index, reweighted annually according to the most recent pattern of trade. Cotton had a very big weight in the 19th century.

In the 19th century rapidly developing Europe required paper in increasing quantities. Originally, the main papermaking materials in Europe were rags, textile fabrics and residues but their supply became gradually insufficient to feed the papermills. This led to the use of wood for papermaking: in 1840 a German patent was granted for a machine grinding wood into pulp for making paper and the first groundwood paper is recorded as having been produced as early as 1841 in Malifax. In the 1850s, paper was already being made from chemical woodpulp which became the chief base material for papermaking (though a small quantity of rag paper is still being made for special requirements). Further increases of demand for paper led to its recycling which again required a number of new techniques, such as e.g. de-inking (Carter and Williams, 1957).

Another industry suffering from base material scarcity was that of soap and candle making. These were made with animal fats; when a fundamental shortage developed fats were replaced by vegetable oils which were acceptable in the kitchen but not by industry where hard fats were required. The problem was solved by the important innovation of chemically hardening liquid fats which were in plentiful supply in the form of whale oil, seed oils etc. (Jewkes, 1969).

The fat shortage, however, did not stop to haunt industry; during the 1914-8 Great War fats of all description were almost unavailable in Germany, where under the pressure of shortage the first synthetic detergent was developed. It was not a very satisfactory - typical 'Ersatz' - product but it represented the first step in the long chain of development eventually resulting in the detergents as known at present. The same fat shortage led to the process of making glycerine, needed for explosives, by the fermentation of sugar residues. The most important among German technical innovations was in those years Haber's nitrogen fixation process that bridged the gap felt by Germany caused by the British blockade depriving them of the imports of Chilean nitrates (Haber 1971). On the British side the most noteworthy innovation was Weizmann's process of basing acetone, another indispensable ingredient of explosives, on the fermentation of ordinary grain when the earlier base material, special temperate hardwoods, became unavailable (Barnett and Morse, 1963).

The best known example of the effect of wartime pressure on material supply and advance in this area during the 1939-45 world War is that of synthetic rubber. Although already between 1900 and 1914 some 500 patents were taken out for the manufacture of elastomers from various bases (Haber 1971) it was the Allied blockade that forced Germany, and later the invasion of South-East Asia - particularly Malaya - by the Japanese that pushed the US and the UK, into speeding up research and development in the search for a synthetic substitute for natural rubber - eventually leading to the building up of a powerful industry (Höllscher 1972).

In quite a few cases shortages were not caused by war condition or by some fundamental scarcity: they were just man-made. In the 1830s a severe shortage of sulphur developed when a French syndicate wanted to exploit Sicily's monopoly of supplies; the answer was the then new process of making sulphuric acid from sulphides and the discovery of pyrite deposits in various parts of Europe (Landes 1969). Around 1895, camphor was in very short supply, as the result of the Japanese occupation of the island of Formosa, at the time the near-monopoly supplier. It sparked off the eventually successful search for synthetic camphor (Rosenberg, 1969). This latter, however, had an important side-effect: Baekeland, a Belgian scientist working in the US, started his experiments in search of some process producing camphor; when this was unsuccessful he searched for synthetic shellac and eventually invented the first of the major synthetic materials (which later on acquired the blanket name of 'plastics') called after him bakelite (Jewkes, 1969).

Materials history produced two curious examples of 'twin' inventions; these concern dyes and aluminium. Dyes of natural origin have been used from time immemorial, going back to biblical times (Bible, Exodus 25:4). With rapid industrial advance it was fairly obvious around the middle of the 19th century that demand would soon outstrip supplies. In 1856 Perkin, a young chemist in the UK. was first to produce a synthetic aniline dye, mauveine. He continued working on alizarine dyes and found a solution but was beaten by the German BASF company applying for a patent based on German work, one day before him. That was the first step in dye developments, followed - among many others - by Bayer's synthetic indigo in 1880 which contributed significantly to the German domination of this industry early this century (ruining, of course, the natural indigo trade of India) (Freeman 1969).

This was an important stepping stone in the development of the chemical industry, from two angles. First, theoretical chemistry reached the point of finding out chemical structures and building new compounds. Secondly, it was the (German) dyestuff industry which first gave rise to the industrial research laboratory. The later (international) successes of the pharmaceutical and polymer industries applied the same approaches that found their origin in the earlier development phases of dyestuffs.

Aluminium was known since 1825 when Ørsted, a Danish scholar, first isolated it. But it remained a very expensive metal, used as 'silver from clay' for luxury items only (such as cutlery for court banquets, an aluminium rattle for the French Prince Imperial, or a watch charm for the King of Siam - Wallace, 1937). Eventually, in 1886, a successful process of electrolytic reduction was discovered independently but simultaneously by Héroult in France and Hall in the US. This was the beginning of today's aluminium industry, but not without difficulty: marketing proved very difficult because processors did not know how to apply the new metal, what to make of it; only after several decades of uphill fight was aluminium generally adopted in the rising mass production of metal goods.

This is often the case with materials that are relatively new. Tungsten was scientifically known by the end of the 18th century, yet its use in industry did not start before this century, first as lamp filament; by now it is one of the important strategic metals making special steels. Titanium has also long been known but its commercial application started only after the World War; it is now indispensable in many applications (it accounts for 9 % of the airframe structure weight of the 'jumbo' Boeing 747).

Sometimes it is not any particular shortage but scientific advance that produces new materials. Man-made fibres provide the best example. At the earlier time of their invention and commercial introduction there was no shortage of any of the natural fibres. By now the worldwide consumption of man-made fibres considerably exceeds that of the natural products (just as in the case of synthetic: natural rubber); without them there could be a fibre shortage.

Man-made fibres represented entirely new materials. There is of course a long list of them and for the sake of illustration let us mention just three in everyday industrial use: cellophane, glass fibres and the already large and ever growing family of plastic materials.

Mention should also be made of the advances of the chemical industry in areas that are not directly affecting industry as a user: in human medicine, where the best known milestones were aspirin, insulin, sulpha-drugs and the family of antibiotics that started with the discovery of penicillin; as well in agricultural chemicals - fertilizers, pesticides and herbicides - which have become equally indispensable in that sphere.

Three further examples should demonstrate, by very recent cases, that progress in the materials area does not stop. With the growing industrial application of natural diamonds supply could not keep pace with requirements: synthetic polycrystalline diamonds are now perfectly competitive with the rare natural stones. Only limited resources of natural quartz crystal are known (of a grade suitable for use in electronics); alternative synthetic quartz crystal has been developed and accepted as a substitute of comparable quality. Demand for radium has been growing ever since discovery in 1898 and successful isolation in 1910; man-made radio-isotopes are now replacing scarce natural radium in many applications.[1)]

Substitution, design and recycling

By the above random walk in history the aim was to show that many (or most, or all) cases of scarcity have so far been solved by technological progress. Now the part played by technology will be discussed from three other angles: substitution, design and recycling. These are not quite independent from each other.

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Some of the cases mentioned above are clearly of a substitutional character, such as the major innovations that resulted in the families of man-made fibres, plastics or synthetic rubber, among others. There are then many cases of one natural or other material replacing another; just a few examples will suffice. Glass-reinforced plastic has been used instead of asbestos in some constructional uses (because of the possible cancer-causing effect of the latter). Aluminium substitutes copper is many electrical uses; copper has also been replaced by steel for shell casings, by plastics in plumbing and by optimal fibres in communication systems. (Enormous quantities of copper are 'sunk' under the surface in all major cities in the form of telephone cables; with their gradual replacement by optimal fibre these will be an important source of secondary metal of high quality.) Lead has been greatly replaced by plastics in construction. The old tinplate cans have practically disappeared: tin-free steel, aluminium and other materials are used instead. In packaging, plastics replaced other materials in many applications, particularly paper.

All these cases were the result of search for 'something other' either because one material became more expensive and a cheaper solution was the aim, or some other reason - easier to work with, for example - provided the incentive. In a few cases the search went as far as making the original base material redundant by re-designing the product or the technology. One of the major uses of silver was in photography - nowadays silverfree photographic material is a commonplace. Different technology entirely bypasses the use of mercury in the chlorine-alkali industry - and so forth.

The technological possibilities of substituting one material for another which is in shorter supply are well demonstrated by Mason (1978) who wrote of the wartime experience of Germany as follows:

> "It became a continued and increasing source of astonishment to me how Germany, with relatively small supplies of metals and minerals, could achieve such large output of trucks, planes, munitions and other war material, outputs that expanded steadily from 1939 to 1944 despite growing losses from aerial bombardment".

1) The contribution of science and technology to the supply of industrial materials, scarcities and allied questions are discussed in greater details in Ray 1975 and 1980.

He then continues, using the findings of the investigations of the US Strategic Bombing Survey, and states that this was achieved "mainly by the substitution of relatively plentiful for relatively scarce metals; the re-design of equipment eliminating or curtailing scarce metal requirements; extensive collection of scrap; and of course the paring or civilian requirements". Iron radiators were substituted for copper ones in all motor vehicles; vanadium and silicon for less plentiful alloy metals such as nickel and molybdenum; but apart from substitution redesign of equipment also played a significant part. At the beginning of the war railway locomotives contained, on average, 2300 kg of copper - by the middle of 1943 this was reduced to 237 kg, one tenth of the original; the original 56 tons of copper in a submarine was reduced to 26 tons.

These examples not only indicate the significance of substitution, they also show - together with some others already mentioned, such as the case of synthetic rubber in both Germany and the USA - that real emergency can give a dramatic boost to technological ingenuity. The driving force is less in peacetime but it is operating nevertheless, for reasons ranging from simple cost reduction to some technical problem, environmental hazard or just scientific zeal.

There have always been opponents to synthetic products advocating the return to the natural ones. The two most powerful arguments are: that synthetics are not of comparable quality and they consume energy 'unnecessarily'. Before taking these in turn it has to be pointed out that the arguments against synthetics are totally unrealistic because they border on the impossible from another angle: cutting out synthetic rubber would require the trebling of natural rubber production; similarly, in the case of fibres, the doubling or trebling of cotton and wool output would be required. The agricultural area for such an increase is simply not available. The impossibility in the case of metals is not that obvious, but even there: it was in the middle of the 1970s that the production of various types of plastics worldwide reached 50 million tonnes. If the products made from them were still needed - which is a reasonable assumption - 50 million tonnes of other materials would be required (e.g. zinc for gutters, aluminium for stepladders and buckets, wood and steel in countless end-uses etc) even if the specific characteristics of plastics (specific weight, durability, corrosion resistance etc) are disregarded.

But apart from this impossibility, there is a grain of truth in both objections. It has often happened that the synthetic material at the time of its introduction was not quite comparable in quality to the natural or traditional product. This was the case of the German man-made rubber (the 'Buna'), the very first synthetic rubber varieties in the US, or the first detergent the Germans manufactured during the first war. But the final product is always different from its very first appearance, when it comes out of the workshop of the innovators; it is the combined outcome of many incremental innovations, additional improvements. By chemical manipulation and other perfection the man-made material's properties can be - and have been - changed. Natural rubber has given general characteristics; synthetic rubber initially was inferior but by means of improvements some years later started to approach comparable quality, with one great advantage however: whilst natural rubber always (or almost always) retains its original 'general purpose' nature, the synthetic product can be formulated to serve specific aims much better. It is the case of the specialist against the general practitioner. Frequently the mixture of the two, the natural and the man-made, gives the best performance (such as e.g. in the case of textile fabrics consisting of cotton or wool plus man-made fibres).

Every new material requires considerable energy input. This is undeniable, but the argument is considerably overdone. It can also become definitely counter-productive: in many cases the synthetic product requires less energy than the traditional one it replaces. Table 1 gives some examples in both specific and general terms.

Table 1. The energy content of selected synthetic and conventional products

		Kg of oil equivalent [a] needed for given production
(i)	Selected typical products[b]	
	fertiliser sacks (100)	
	paper	39
	LD-PE	35
	pressure pipe (100 m, 25 mm ø)	
	iron	500
	copper	96
	HD-PE	38
	drain pipe (100 m, 100 mm ø)	
	cast iron	1970
	clay	275
	PVC	154
	one-litre bottles (100)	
	glass	23
	HD-PE	12
	PVC	8
(ii)	in general terms:[c]	
	aluminium	15
	copper	11
	steel	8
	nylon, acetate resins	4
	others [d]	1 1/2 - 2

Source: The Economist, 3 November 1979, based on BASF.

a) The amount of oil equivalent includes energy used in the production of the items listed as well as the energy content of the basic materials used. The figures are rounded. Those for synthetics are underlined.

b) Units and definition (where needed) in brackets.

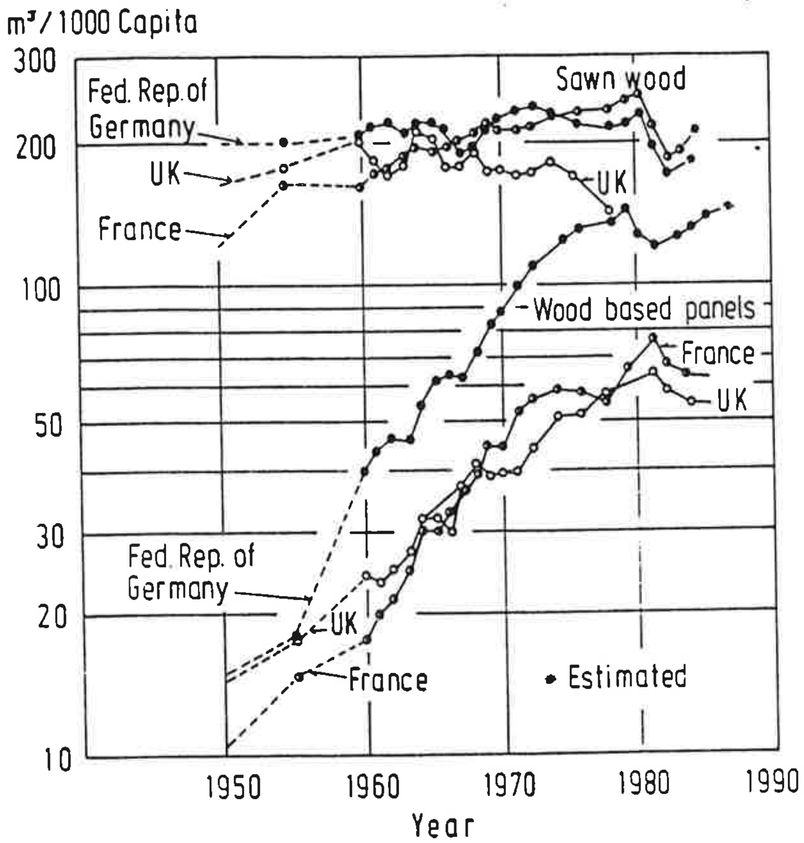
c) The data refer to a 'one litre' unit.

d) Copolymers, polystyrene, high and low-density polyethylene (HD/LD-PE), polyvinylchloride (PVC) and prolypropylene.

Design affects another aspect as well of the metal and other trades: recycling; as the operation of regaining materials from an end-product for renewed use, it has become an important source of supply. The quantity of recycled metal varies somewhat, influenced by the current price of primary metal. Scrap recovery yielded, in the past 20-25 years, quantities equivalent to significant parts of the consumption in the Western world: one half of copper and lead, one third of zinc, and one quarter of aluminium and tin. The recycling of some other materials, such as glass and paper, also contributes to supplies. More recently a certain amount of technological effort has been directed into problems allied to recycling, partly under environmental pressure. Much depends on the design of products; in frequent cases re-designing them with a view to easier recovery of the embodied materials would greatly help. The motor car is a case in point it incorporates a large quantity of various metals and other materials but at present largely in a way which makes them difficult and costly to disentangle (with the exception of the rubber in the tires and the lead in the battery).

Recycling waste and combining it by upgrading lower quality material occurs in some branches; outstanding among them is the wood industry. Plywood and other wood panels, widely used in construction and in the wood/furniture industries, are made of waste wood, rejects and offcuts, as well as from small diameter wood (not suitable for sawnwood) by means of developed technique of grinding, gluing and laminating. The resulting wood-based panels have been widely accepted, used in increasing quantities and thereby helped conserving forestry resources. Chart 1 indicates that in the three largest European timber-consuming countries, German, France and the UK, the consumption of sawnwood remained fairly stable in postwar decades whereas the use of wood-based panels rose very rapidly indeed (Chart 1).

Chart 1. Consumption of sawn timber and wood-based panels in Western Europe



Source: H.J. Deppe, Renewable materials: wood and wood-based materials. Fifth issue of the Bulletin of the Advanced Technology Alert System (ATAS): Materials Technology and Development, United Nations, New York, 1988. p. 54.

Technology in production

Whilst scientific and technological progress greatly contributed to the supply of minerals and metals in the past by means of discovering and inventing new materials and other ways as described above, its greatest impact was on the production side; in exploration, mining and processing.

The exploration phase well demonstrates how advances in many different areas of science can be coordinated. In earlier times exploration meant cumbersome drilling. Nowadays this is supplemented by many advanced methods such as quantifying gravity variations, studying magnetic and electric reactions of an area, the use of seismology, analysis of the local flora for mineral content, aerial photography and so forth. Satellite photography discovered metal deposits in areas - in the US, for example, - where earlier conventional geological methods found nothing worthwhile. Offshore exploration is another new departure which may eventually lead to seabed mining (on which see more later).

Exploration is usually aimed at finding new sources of a material which is known. But there is another avenue of research too. Originally, there was only neutral matter in nature: a material became a natural resource when man began to use it for a specific purpose. Take the example of aluminium: bauxite did not even have a name before it was discovered that it could be processed into aluminium; with the spread of the use of this 'new' metal the search continued for other possible base for its manufacture given the geographically limited occurrence of bauxite, with the result that by now several processes are known for aluminium manufacture which use Al-containing clays other than bauxite. (One part of the Soviet aluminium industry is based on them.)

Mining proper takes two main forms: deep and strip (or opencast) mining. In both changes had been dramatic. Deep mines were traditionally characterised by permanent struggle against underground water and methane explosion - a far cry indeed from today's remotely controlled automatic mining equipment. In North America, some three quarters or more of all mineral output comes from open pits; in these strip mines, on average, about two tons of overcover are removed to obtain one ton of (often very 'lean') ore. All this means earthmoving and transportation operation on enormous scale. Accordingly, the mule cart was gradually replaced by more progressive methods, eventually into today's sophisticated conveyor systems.

More noteworthy are, however, the developments in processing technology. Let us take copper for illustration. In the early part of the 19th century Cornwall was the leading world producer; the metal content of Cornish ore was 13 % and the price of copper in 1821-30 was £ 101 per ton on average (during the Napoleonic wars it reached £ 160). Cornish ores became exhausted and by about the middle of the century Anglesey was the centre of copper mining; the UK remained the leading producer with output of refined copper reaching 11.800 tons in 1850[1]; the Cu content of Anglesey copper was 'only' 3 %. At about this time US copper output started to rise rapidly; the average metal content there was 2 1/2 - 3 % at the time. Many of the new mines in the US and elsewhere now contain no more than 1/2 - 1 % metal.

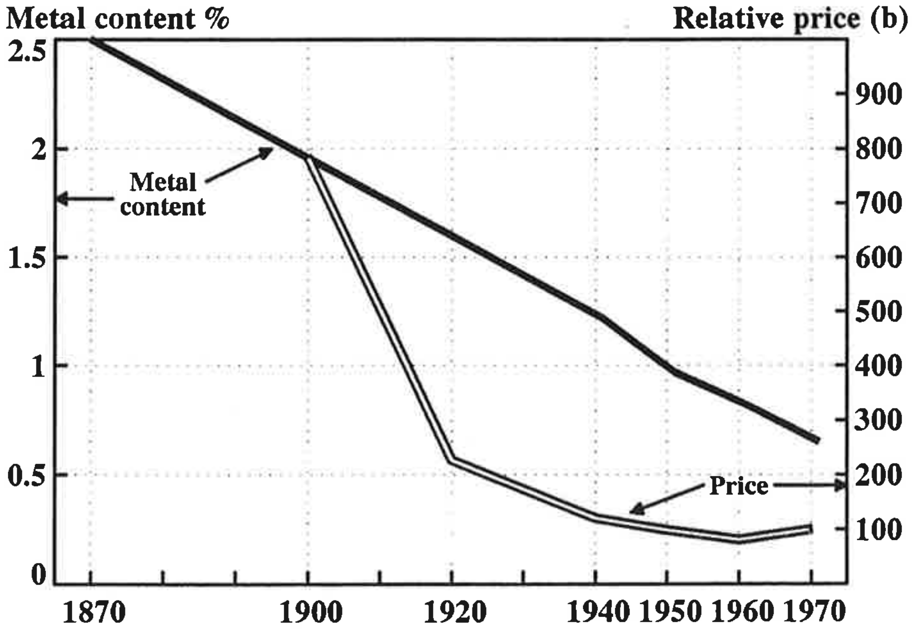
By 1850 despite the lower content of Cu in UK ores, the London price of copper was down to £ 87/ton, well below the average of the 1820s, despite the lower metal content of the ores. This trend then continued. According to the calculations of Nordhaus (1974) the real price of copper in the

1) World production in 1850 amounted to 52.250 tons; Major producers apart from the UK were South America (Chile and Bolivia mainly) 14.200 tons, Russia 6.000 tons and the USA 2.700 tons. (Cordero and Tanning, 1960).

1960s was only one eight of the price around the turn of the century, seventy years earlier (Chart 2). Thus, technology worked in two directions: first, that ores with gradually lower and lower metal content could be processed into refined metal, and secondly, that not only were they economically capable of being transformed into metal but the cost and price of the metal could be significantly reduced.

The steel industry offers many examples of technological change; only three will be cited. After being practically useless for previous technologies, high-phosphorous iron ores were brought into the ambit of valuable resources by the late 19th century development of the Thomas process; the French steel industry in the Lorraine was based on them. When the high-grade iron ore deposits in Minnesota approached exhaustion at around the middle of this century the huge inland iron and steelworks in the US had two obvious choice: relocate near the cost to use imported high-grade ore or carry the high cost of transporting the ore to them. Technology saved them, however, by pelletising low-grade 'taconite' ores (of which US reserves are immense) and thereby making them 'artificially high-grade'. In the sixty years ending around 1970 the US blast furnaces reduced their specific ore requirements by 17 % and the quantity of coke used by almost 50 % (Rosegger 1975). Comparable saving in the usage of coke for pig iron was achieved by the German industry too (Ray and Uhlmann 1979).

Chart 2. Copper: the average metal content of ore produced and the relative price of refined copper [a)]



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Source: for ores, Dunham, 1974; for prices, Nordhaus (ed.) 1983.

a) All data concern the USA except for 1870 which indicates the ore content of Anglesey (UK) copper, the price leader at the time. In the first half of the 19th century Cornwall (UK) was the leading producer: the Cu content of Cornish ore was about 13 per cent.

b) Price per ton of copper divided by the (US) average hourly wage rate in manufacturing, 1970 = 100.

So far we have surveyed and illustrated many aspects of the part played by technology in helping to secure the supply of non-renewable industrial materials. But whatever direction progress will take in the next quarter-century, in whatever degree it will succeed to expand the resource base, the world's reserves are - and will remain - finite. Will their finite nature jeopardise the availability of those supplies the world will require around our target year: 2017? In order to approach a possible answer we turn now to the question of reserves.

Defining reserves

What is generally meant by 'reserves' is those quantities of minerals or metals that are known and proven to exist and are economically exploitable under given technological conditions. Reserves constitute a part of resources (of a given metal, for example), the latter including deposits not yet known and proven and/or not exploitable at present economic conditions. An allied concept - admittedly a more theoretical one - is that of the resource base, test approached by the crustal abundance of the earth: "A cubic kilometre of the earth's crust contains some 200 million tons of aluminium, 100 million tons of iron ore, 800 thousand tons of zinc and 200 thousand tons of copper" (manners 1977) and of course many other types - but estimates of this kind may never become a realistic base for supplies because of prohibitive costs or technical impossibility.

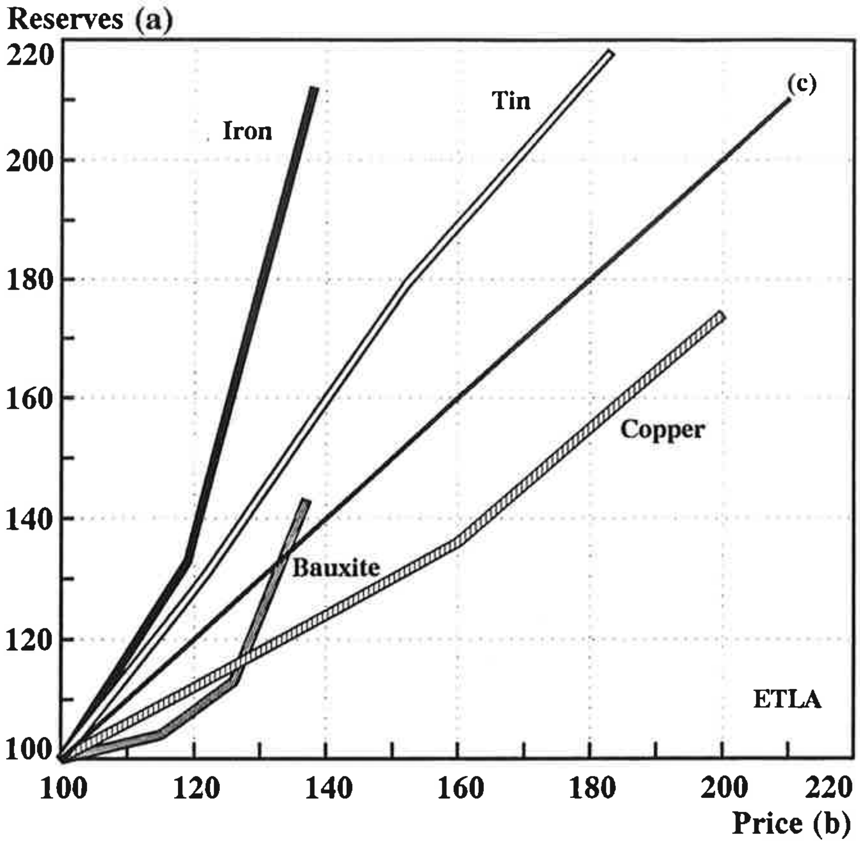
The above definitions leave several doors open. Resources and reserves are dynamic concepts. As use is found for materials hitherto considered just neutral natural matters, they become resources. No one has been motivated as yet to find out the absolute limit of resources of any material. Producers of any mineral are generally quite satisfied if the known reserves cover 10-20 years' requirements; they are, as a rule, not making efforts for exploring additional reserves that would not come into production for over twenty years. As the known reserves are exploited further areas are explored and new deposits found which add to the reserves.

It is worth remembering at this point that a very large part of the earth has never been properly explored. There are huge areas - in South America, for example - geologically classified as rich in minerals and yet only partially explored. Modern techniques help the discovery of major mineral deposits even in well explored areas such as the USA.

Much depends on the economic feasibility - in other words: on price. At higher prices it becomes worthwhile to exploit reserves that are not considered commercially viable at lower prices. Higher prices made it possible to reopen the Cornish tin mines (or indeed King Solomon's copper mine in the Negev desert) - with the fall of the price they were again taken out of production. In the first half of the 1980s the decline in prices (relative to costs) led to reductions in the reserve estimates of several metals, as earlier economic ore bodies became uneconomic.

Estimates made a few years ago and reproduced in Chart 3 indicated that a 40 % increase in the price of iron ore, or a doubling of the price of copper or tin, would double the reserves which are commercially exploitable. This relationship between price and reserve may change but for most minerals the general tendency is valid. (Houthakker 1976). The view is based on the crustal abundance already mentioned; the average metal content of the earth's crust is much lower than that of the ores mined at present. But as detailed earlier, the advance of technology has already gradually reduced the lower limit of commercially exploitable resources (by economically producing metal from leaner ores) - and this process will no doubt continue. The cut-off point will always depend on technical progress.

Chart 3. Commercially recoverable resources of four major ores under selected price assumptions.



Source: Bosson and Varon (1977), page 226.

a) Estimated reserves at given price levels, 1969=100
b) 1969=100; in constant 1969 dollars
c) 1 : 1 relationship.

The utilisation of increasingly diffuse ores may be limited by other considerations such as high energy requirements, environmental problems posed by dealing with the waste produced or the disturbance caused to nature by the extension of mining. At this point again, technological change will step in: it can take a number of forms ranging from substitution to the transformation and redesigning of the final product.

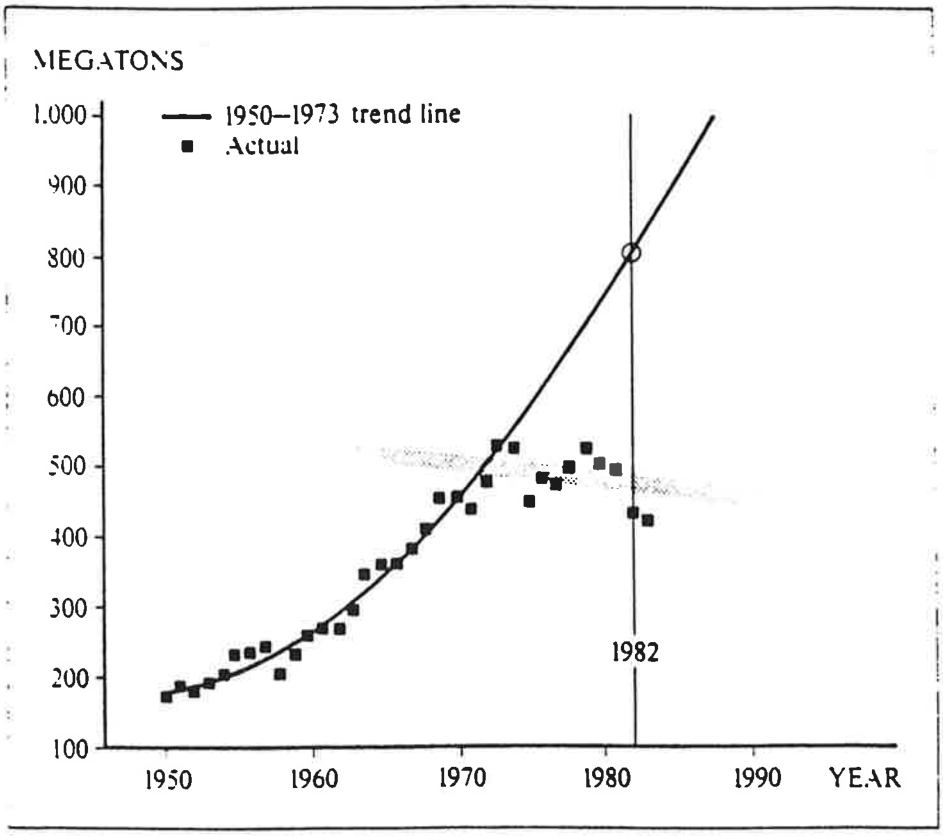
The assessment of the adequacy of reserves is generally based on an indicator that estimates the lifetime of current reserves assuming some future exploitation. Exploitation of course depends on the demand for any given material - which can, naturally, change over time. Various assumptions can be used, particularly if some longer period is being surveyed; because of the uncertainty surrounding future demand the continuation of the current consumption is usually presumed. This can be modified, as a second step, in line with expectations of increasing or decreasing use.

Demand

Requirements for minerals and metals are determined by three main factors: the growth of the economy in general, as measured by GDP; the structure of that national output and its change; and the metal intensity of the sectors of the economy directly consuming metals. All three have changed considerably during the past decades, pointing to the dynamic nature of demand. The year 1973 and the subsequent years appear to have been the watershed. Economic growth slowed down significantly around those years. The growth rate of real GNP in the seven major industrial countries was 5 1/4 % a year in 1962-73, followed by 2 1/2 % in 1973-80, continuing at 2 1/2 - 3 % in the 1980s. Industrial production and investment activity slowed down almost similarly. Moreover, the lowering of growth rates was more pronounced in Western Europe than elsewhere - and Western Europe accounts for a large share of world metal use.

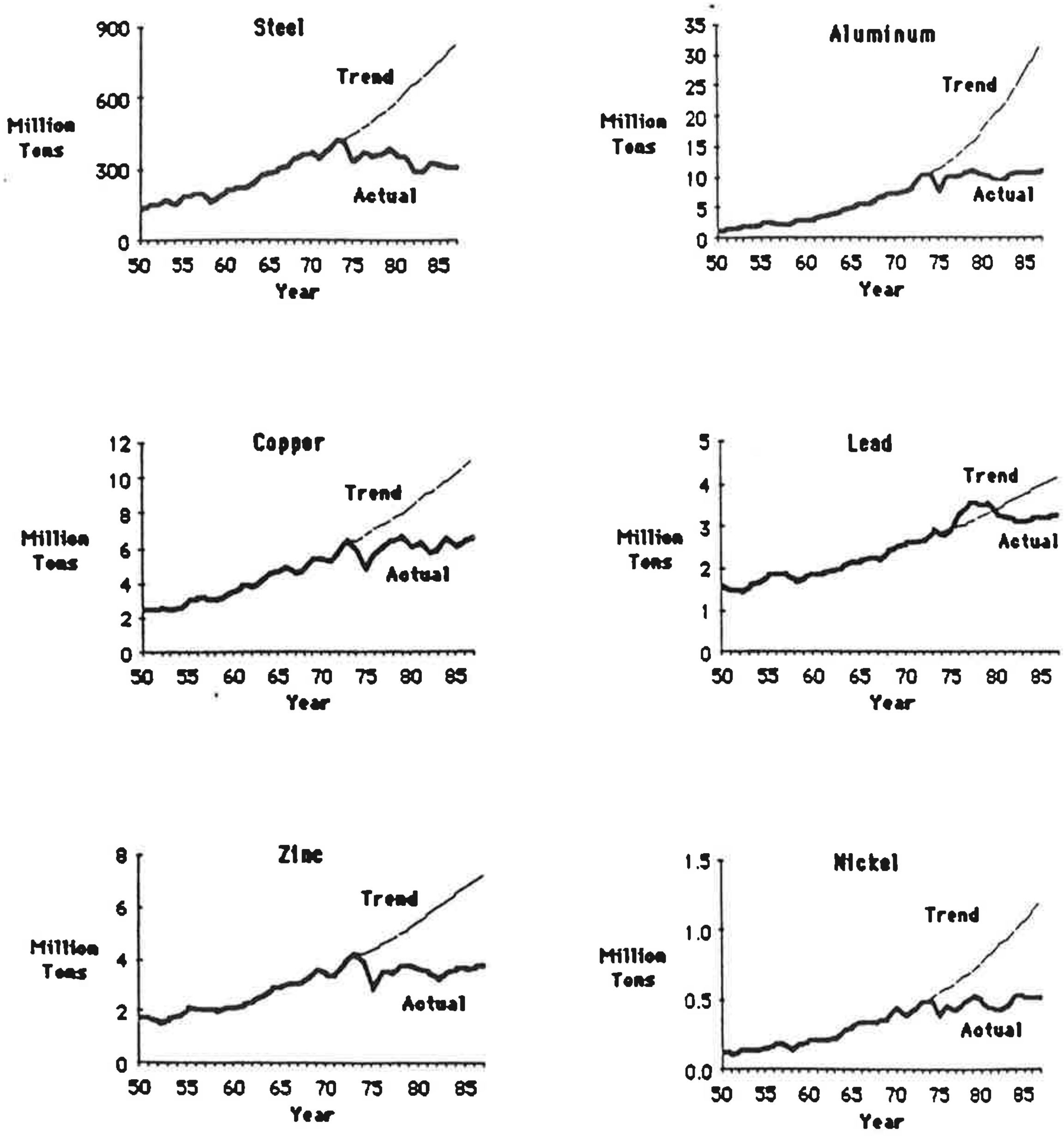
The structure of national output has also been changing. The service sector's share in output has been increasing, particularly in advanced countries (that is: the largest users of metals); relative to the value produced services require less input of materials than primary or secondary activities.

Chart 4. Western world steel consumption, 1950-1990



Source: Murthy and Taylor, 1988.

Chart 5. Consumption of Steel, Aluminium, Copper, Lead, Zinc, and Nickel, Actual and Trends, 1950-87



Notes: Consumption generally is for refined meal, and excludes the direct use of scrap. Aluminium consumption is solely primary metal. Nickel consumption includes the nickel consumed in nickel salts and other chemicals. Steel consumption figures are for crude steel, and include both primary and secondary metal.

Sources: Metallgesellschaft Aktiengesellschaft (annual) for aluminium, copper, lead, zinc, and nickel; International Iron and Steel Institute (annual) for steel. From: Tilton, 1988.

Perhaps the most important was, however, the reduction in the intensity of metal use. This is demonstrated by statistical observations. Steel is the most important of base metals, used in the largest quantities. As Chart 4 indicates, Western world steel consumption showed a sharply upward trend; that was broken in the mid-1970s and by the early 1980s a new, downward tending (or at least stable) trendline was recognised. The chart demonstrates this change as of 1982 and although there have been ups and downs in the later 1980s, the very strong modification of steel usage trend during the quarter-century ending in the mid-1970s has by now been firmly established.

Chart 5 illustrates that his change was not unique to steel: OECD consumption of all major non-ferrous metals also developed similarly.

So far we have dealt with total consumption and a part of the decline in metal use was obviously due to the slower growth of output. In table 2 the consumption of the main non-ferrous metals is related to industrial production, making allowance for slower growth; the countries included are the seven major OECD countries and the USSR. Table 3 gives a more aggregate information for the same metals, relating their consumption to the two major output indicator: GDP and industrial production, for three categories, the four large European countries, the seven large OECD countries and the eight most important industrial countries (the seven large OECD countries plus the USSR). All data concern primary metals.

Table 2. The consumption of main non-ferrous metals related to industrial production in the seven large OECD countries and the USSR. 1976-87

1976 = 100

	ALUMINIUM				LEAD				COPPER			
	1980	1983	1986	1987	1980	1983	1986	1987	1980	1983	1986	1987
USA	87	80	72	74	74	77	67	69	89	95	86	86
Canada	69	72	76	96	89	77	67	70	91	89	84	82
Japan	82	83	71	71	103	90	84	80	89	89	78	80
France	112	117	111	115	86	81	83	81	109	100	101	97
Germany (a)	99	108	106	105	101	100	102	98	91	94	88	90
Italy	109	111	122	126	90	84	78	77	105	95	107	109
UK	87	68	76	72	88	86	77	76	85	73	64	60
USSR	91	82	67	69	95	86	72	71	87	78	69	69

	ZINC				TIN				NICKEL			
	1980	1983	1986	1987	1980	1983	1986	1987	1980	1983	1986	1987
USA	70	74	69	71	74	56	47	50	83	79	63	69
Canada	86	92	80	84	84	66	57	61	90	75	73	86
Japan	87	85	72	68	72	68	61	61	87	76	74	87
France	114	96	91	86	89	68	67	63	105	91	88	105
Germany (a)	113	118	113	117	92	86	94	94	109	106	130	125
Italy	101	96	99	101	86	72	83	85	107	97	117	110
UK	71	68	58	65	65	62	55	54	71	66	78	90
USSR	92	85	72	70	91	88	93	84	90	90	75	74

Source: Metall-Statistik, Metallgesellschaft AG, Frankfurt a/M; UN Monthly Bulletin of Statistics; National Institute Economic Review.

Note: Metal consumption data concern primary refined metals, excluding recovered scrap (a) West Germany.

Variations by country are quite large, depending on the structure of industry, the importance of metal-hungry branches such as motor vehicles etc. nevertheless the unmistakeable message of the tables is the almost universal decline in the relative use of metals. Taking the arithmetic average of the data for the six non-ferrous metals, their consumption in the second half of the 1980s was, related to output, some 30 % lower in the USA than ten years earlier; the comparable figure was 25 % in Japan, 9 % in the four large West European countries and 27 % in the USSR. There is every reason to believe that metal usage, in these terms, declined similarly in other advanced industrial countries as well.

In some countries, aluminium, nickel and zinc appear to have been used in increasing quantities. The case of aluminium is explained by the trend toward lighter products, the higher use of nickel is mainly due to the expanding application of stainless steel, whilst some carmakers started to use zinc-coated steel to give longer protection against rust.

The reduction of metal intensity is another manifestation of technological change; it has worked in four main ways.

Table 3. The consumption of main non-ferrous metals related to national output and industrial production in major industrial countries, 1976-87

1976 = 100

		ALUMINIUM				LEAD				COPPER			
		1980	1983	1986	1987	1980	1983	1986	1987	1980	1983	1986	1987
(A) Four large European countries[b]	P	101	96	97	95	91	82	80	78	94	84	82	82
	I	101	103	104	103	92	88	85	83	95	90	88	88
(B) Seven large OECD[c] countries	P	123	114	107	108	85	80	74	73	93	90	83	83
	I	121	117	109	112	84	82	75	75	92	92	86	86
(C) Eight large industrial countries[d]	I	115	109	100	102	87	83	74	74	91	89	82	81

		ZINC				TIN				NICKEL			
		1980	1983	1986	1987	1980	1983	1986	1987	1980	1983	1986	1987
(A) Four large European countries	P	100	90	82	87	80	68	70	69	99	86	95	102
	I	101	96	88	93	80	73	74	73	100	92	102	109
(B) Seven large OECD countries	P	87	83	76	77	77	64	59	60	92	82	79	87
	I	86	86	77	79	76	66	61	62	91	85	80	89
(C) Eight large industrial countries	I	88	86	78	77	78	69	65	64	91	86	79	86

Source: as for table 2.

a) Weighted by 1980 data
b) France, West Germany, Italy and the United Kingdom
c) (A) plus the United States, Canada and Japan
d) (B) plus the USSR
e) P = related to GDP/GNP; 1 = related to industrial production.

First, the explosion of commodity prices and of the oil price in 1973-4 led not only to energy 'conservation' but also to the more efficient use of metals. Higher energy prices triggered off the tendency towards lighter end-products: existing products started to be made in lighter variations or in smaller size, often going as far as miniaturisation with the help of microelectronics. Data relating to the US automobile industry should serve as illustration: in the ten years to 1986, the average steel and copper content of US-made passenger cars was reduced by one fifth, the quantity of aluminium rose by some 60 % because of the specific properties of this light metal, with the combined outcome of a reduction of total vehicle weight by 16 % (table 4).

Table 4. Changes in materials use in passenger cars in the USA

Pounds per car

	1976	1986	% change
Iron and steel	2841	2245	-21
Plastics and composites	163	216	+33
Aluminium	86	140	+63
Glass	88	86	-2
Copper	32	26	-19
Other materials	551	458	-17
Total vehicle weight	3761	3171	-16

Source: as for Chart 4.

Secondly, industrial growth in recent years has been concentrated on many relatively new products, most of them based on electronics; their metal requirements are smaller than those of the traditional products of mechanical or electrical engineering.

Thirdly, there have been exceptional cases of technological change with a definitely adverse impact on the use of metal. The best known example is the gradual abolition of lead as an additive to gasoline/petrol for use in motor cars - for environmental reasons, as detrimental for health. Recent medical research also pointed to the possible harmful effect of aluminium in food containers; this may lead to the decreasing use of metal in food packaging.

Fourthly and finally: the replacement of metals by non-metallic materials has been growing. Chief among these materials are various types of plastics; they replace zinc and lead in the building trades, various metals in vehicle manufacturing, metal boxes in packaging, and so forth. Optical fibres are used instead of copper in some areas of communication, ceramics replace metals in many engineering applications - and the list can be continued.

Metal intensity naturally changes from year to year. Growth rates in metal consumption during 1988-89 exceeded GDP growth even in the mature industrial countries. The reason was the vigorous expansion of investment and the consequent high demand for metalintensive capital goods. It was probably a temporary phenomenon and metal intensity is likely to return to the lower level of the earlier years of the past decade. Such fluctuations always depend on the structure of demand and production. They will occur in the future as well. Nevertheless, it seems very probable that in the long term metal intensity of national output - at least in the advanced economies - will move on a downward sloping trend, at a rate that can be expected to be somewhat more moderate than in the 10-15 years to 1988.

The lifetime of reserves

In the final analysis it is not the absolute quantity of reserves we are interested in but their lifetime: the number of years they can be expected to satisfy worldwide demand. In other words: their adequacy. This depends on two determinants: the magnitude of reserves and the quantity of requirements. As demonstrated in the foregoing: both are dynamically changing. Looking ahead, into the distance of another quarter-century, the uncertainties of all factors that will shape the development of both sides multiply; thus, any forward estimate should be treated with caution.

The problem of the lifetime/adequacy is approached here in two ways. Both are included in table 5. The first is the static lifetime, in years, of identified reserves, assuming that their exploitation - i.e. mine production - continues at the 1987-88 level. However, in most instances new deposits are discovered, some of the resources are upgraded into reserves by becoming economically exploitable, and existing mines also extend their knowedge and operations.

The second part of the table allows, to some extent, for these future changes. It is intended to indicate "adequacy" by a ratio of the identified reserve base to the foreseeable primary demand to the years 2010, based mainly of historical growth rates projected forward.

It is to be noted that the figures in the second part of the table, i.e. the ratios, are based on the reserve base. Whilst 'reserves' are defined as recoverable materials that can be economically extracted or produced at the time of determination (i.e. a static concept), the reserve base is broader. It can be described as in-place demonstrated (measured plus indicated) resource including those resources that are currently economic (i.e. 'reserves'), marginally economic (marginal reserves) and some of those that are currently subeconomic but are likely to become economic some time during the period under observation. This dynamic ratio is more meaningful than the static reserve: production ratio.

An even broader ratio of resources to cumulative demand would normally be much greater because as prices rise or costs fall more deposits will move from resources into reserves and by this upgrading supplies will be sustained for longer than the ratios given in table 5 suggest.

Among the 46 minerals/metals included in table 5 there are 13 whose static lifetime is less than 25 years. Their situation changes, however, when the more dynamic prospect for their adequacy is considered. The latter indicator being more meaningful than the mere static assessment and therefore we turn now in somewhat more detail to hose materials whose ratio (reserve base: cumulative demand) is less than 1.5. (The estimates in table 5 concern the period to the year 2010; our benchmark year is 2017, therefore we analyze minerals with a ratio of 1.5 instead of 1.0).

Taking them one by one we start with gold, a metal of special properties (and only partially an 'industrial' material); well over one half of gold's end use is in jewellery (86 % in the EC). In 1988, 1,900 tonnes of gold were produced; some 39.000 tonnes are held by central banks as reserves and another estimated 48.000 tonnes held by privates as coin, bullion and jewellery. No other metal has all gold's properties and emphasis is on reduction of gold content. Substitutes nevertheless exist: platinum, palladium, silver and titanium - in certain applications such as electronics and dental work.

Table 5. Reserves and their adequacy [a)]

(1) STATIC RESERVES[a]

25 years or less	26 to 50 years	26 to 60 years	61 to 100 years	101 to 300 years	Very large[c]
Arsenic 24 Asbestos 25 Bismuth 25 Cadmium 25 Gold 22 Indium 17 Diamonds 19 d Lead 20 Mercury 20 Silver 19 Sulphur 24 Tin 21 Zinc 21	Barytes 30 Copper 40 b	Fluorspar 55 Molybdenum 58 Nickel 57 b Selenium 55 Tungsten 59	Antimony 66 Manganese 98 b Tantalum 91 Tellurium 94 Uranium 62 Vermiculite 86 Zirconium 78	Bauxite 217 Boron 289 Chromium 123 Cobalt 123 b Iron ore 122 Niobium 260 Platinum 205 e Rhenium 108 Titanium 116 Vanadium 135	Beryllium Gallium Germanium Lithium Magnesium Phosphates Potash Rare earths Silicon

(2) RATIO OF IDENTIFIED RESERVE BASE TO FORESEEABLE CUMULATIVE PRIMARY DEMAND 1989-2010[a]

1.0 and less	1 to 2	2 to 4	4 to 10	10 to 45[f]	Very large
Gold 0.8 Tantalum 0.9 Tin 0.7	Arsenic 1.3 Asbestos 1.3 Cadmium 1.7 Copper 1.9b Fluorspar 1.9 Indium 1.4 Diamonds 1.3d Lead 1.4 Silver 1.1 Zinc 1.6 Zirconium 1.7	Antimony 2.7 Barytes 3.2 Bismuth 2.5 Molybdenum 3.9 Selenium 3.5 Sulphur 2.3 Tungsten 3.1 Uranium 2.5	Chromium 7.1 Iron ore 8.2 Nickel 4.9b Niobium 5.2 Phosphates 8.0 Platinum 9.0e Tellurium 5.9 Titanium 4.1	Bauxite 12 Boron 19 Cobalt 13b Lithium 40 Magnesium 11 Manganese 16b Mercury 42 Potash 37 Rare earths 35 Rhenium 18 Vanadium 18 Vermiculite 12	Beryllium Gallium Germanium Silicon

Source: Crowson (1990).

(a) For definition and explanation of parts 1 and 2 - see text. In the first part, the number attached to each metal indicate years, on a static basis. In the second part the figures show a ratio; a ratio of 1.0 indicates that the identified reserve base exactly (=approximately) covers the foreseeable demand to the year 2010 whilst the ratio 2.0 indicates that the reserve base could cover twice the foreseeable demand. The data reflect the 1988-89 position.

(b) Land based reserves only, not including the possible yield of deep-sea mining.

(c) Large or very large.

(d) Industrial diamonds only.

(e) Including all platinum group metals.

(f) The years are rounded in his column.

Tantalum's main end-use is in the making of electronic components, cutting tools, carbide and various industrial applications. There is a long list of substitutes, though admittedly at the expense of performance of cost. Tin: this is one of the major metals, mainly used for tinplate, solder, alloys and chemicals, apart from a small quantity used as wrought tin. Many substitutes exist and technological progress not only provides alternatives but reduces the tin needed for tinplate, for example. Besides, whilst 1988 mine production was about 200 thousand tonnes and the world's reserve base is 4,4 million tonnes, identified world resources amount to an estimated 37 million tonnes. It will depend on the price when the latter will gradually be upgraded into reserves.

Arsenic: Mainly used in industrial and agricultural chemicals; it is substitutable in most applications - probably a welcome move in view of the increasing environmentalist pressure against arsenic use.

Asbestos: Greatly tightened health regulations are hastening the replacement of asbestos, believed to contribute to developing cancer, in all uses in developed countries. Among the alternatives are glassreinforced cement, natural and artificial fibres, ceramics and plastics; their application is forced, almost regardless of the technical difficulties and costs involved.

Indium: Major end-uses include electronic components, plating, alloys and nuclear reactor control rods. Substitutes exist for most of them.

Industrial diamonds: Synthetic diamonds are accepted substitutes in almost all applications; other abrasive materials are also being brought into the market. In 1988, 50 million carats of industrial diamonds were min-produced; in the same year synthetic production reached 250 mn carats (which was just under 70 % of productive capacity).

Lead: Another of the major metals. It is worth quoting some estimates that show enormous differences between reserves and other quantifications: lead reserves (in contrast to a mine production in 1988 of 1,7 million tonnes) are estimated worldwide at 70 mn tonnes, the reserve base at 120 mn tonnes, but total world resources at 1,4 billion tonnes! Lead will be gradually phased out as an additive to motor spirit. The tendency is for reducing the amount of lead per battery, and by technological improvement battery lives are being extended; possibilities for excluding lead entirely from batteries are being actively pursued (nickel-zinc, zinc-chloride and other solutions). Polyethylene and other materials substitute lead in cable covering, glass, plastics, processed steel etc. in other applications.

Silver: A major end use of silver is in photography (some 50 %); silverless black-and-white film and xerography, video and ultrasonic scanning have already replaced or are threatening silver-containing photographic film. Stainless steel in tableware, aluminium and rhodium in reflecting surfaces, tantalum in surgery - these are replacement for silver in non-investment applications.

In the 46 minerals included in table 5, there were only nine with an adequacy ratio of 1.5 or less; the identified reserve base of these minerals appears to cover cumulative requirements in the next about 25 years - and not longer. The lifetime/adequacy of all other minerals/metals is much (in many cases very much) longer/greater. Moreover, as the foregoing brief survey indicates, even in the cases of the minerals with the lowest adequacy ratios, there are ways and means to replace them in time of scarcity by other, more plentiful materials.

Two important additional remarks should be made. First, that technological advance will help to overcome possible scarcities; there have been plenty of examples in the past. many of them mentioned earlier in this paper, pointing in this direction.

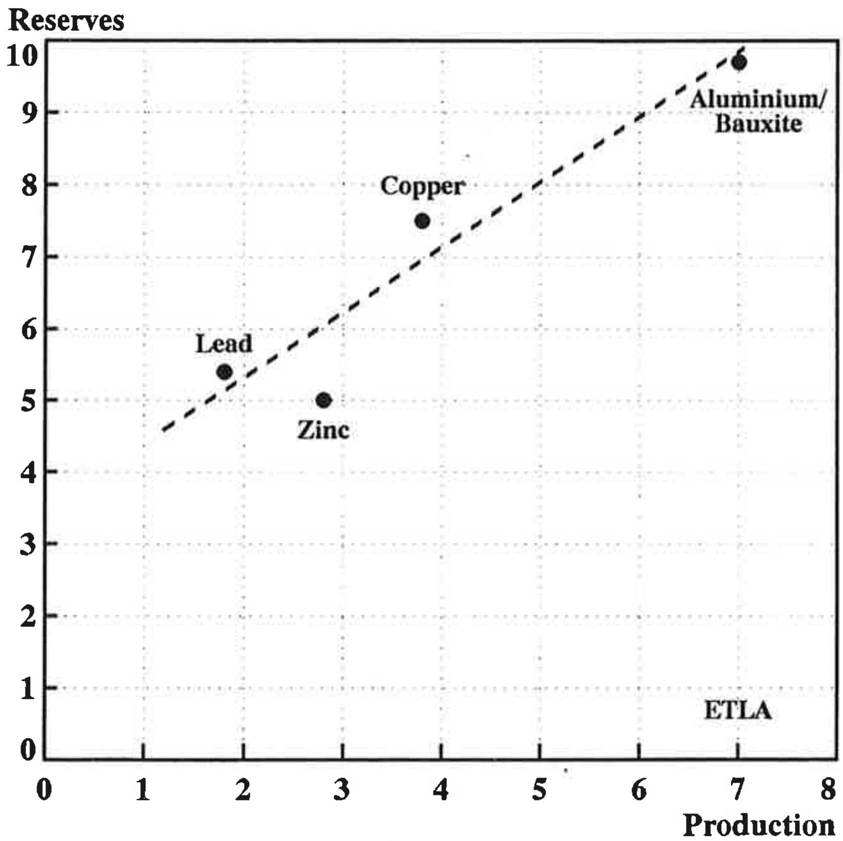
Secondly, reserves - in general - grew faster in the past than world mine production. This is shown in chart 6, concerning four major base metals: copper, lead, zinc and aluminium. This pattern is rather typical for most other metals too. From the 1950s to the end of the 1970s reserves increased much faster, in some cases twice as fast, as mine production. Then in the first half of the 1980s a decline in prices relative to costs led to reductions in reserves (hitherto economic ore bodies became uneconomic); the position was not fully reversed in the second half of the 1980s. Therefore, production tended to rise more rapidly than reserves in the 1980s, but not by enough to invalidate the longer term trends.

Security of supply

Adequacy, however, is not identical with security. While adequacy, at least in this paper, is treated as a long-term concept, the security of supply conveys a more short-term point of view (though it can of course have a long-term meaning as well).

Chart 6. The growth of reserves and production of four major non-ferrous metals, 1950s to 1970s

Annual average per cent changes



Source: Crowson 1990.

The relationship between growth of mine production and growth of reserves is:
$RE = 3.467 + 0.901P \qquad R^2 = 0.897$
where RE = per cent change in reserves and P = per cent change in production.

Table 6. The import dependence of the EC-12 countries, 1988

Percentages [a)]

0-24%	25-49%	50-74%	75-99%	100%
Arsenic 23	Aluminium 48	*Copper 62	Antimony 97	Asbestos
Germanium 9	Barytes 36	*Zinc 71	Bismuth 89	Beryllium
Sulphur 21	*Cadmium 32		*Chromium 93	Boron
	Fluorspar 27		*Iron ore 90	*Cobalt
	*Lead 37		Magnesium 82	Lithium
	Potash 26		*Nickel 85	Manganese
	Silicon 38		Tin 77	Molybdenum
	*Silver 38		Tungsten 75	Niobium
			Uranium 80	Phosphates
				*Platinum
				Rare earths
				Rhenium
				Tantalum
				Titanium
				Vanadium
				Vermiculite
				Zirconium

Source: Crowson 1990.

(a) Imports as a percentage of domestic consumption plus exports. For metals not shown the indicator is not available (gallium, gold, indium, mercury, selenium, tellurium).

* Minerals/metals marked by an * are being produced in Finland.

Table 7. Concentration of world mineral reserves in particular countries, 1989 [a)]

	Country	Per cent
Antimony	China	52
Asbestos	(Canada	36
	(USSR & China	43
Beryllium	Brazil	37
Boron	(Turkey	33
	(USA	32
Chromium	South Africa	70
Cobalt	Zaire	41
Gold	South Africa	47
Industrial diamonds	Australia	51
Iron ore	USSR	38
Lithium	Chile	57
Magnesium	China	30
Manganese	(South Africa	45
	(USSR	36
Mercury	Spain	62
Molybdenum	USA	49
Nickel	Cuba	37
Niobium	Brazil	78
Phosphates	Morocco b	50
Platinum c	South Africa	88
Potash	USSR	78
Rare earths	China	80
Rhenium	Chile	48
Titanium d	Brazil	78
Tungsten	China	47
Vanadium	USSR	62
Vermiculite	(USA	53
	(South Africa	40
Zirconium	South Africa	38

Source: Crowson 1990.

(a) Countries with at least 30% of world reserves at end-1989.

(b) Incl. Western Sahara. (c) Platinum group of metals.

(d) Titanium in Rutile.

Our above assessment presents a fairly optimistic outlook for the probability of reserves being sufficient to meet long-term requirements; with regard to the security of undisturbed supply further aspects come into consideration, namely the dependence on imports and the concentration of reserves.

The European Community (of 12) is heavily dependent on imports of minerals/metals. In the case of at least 17 minerals 100 % of the EC's needs have to be imported; among them are cobalt, manganese, phosphates, platinum, titanium and vanadium (table 6). Over 75 % of another nine metals also depend on imports, such as chromium, iron ore, nickel, tin and tungsten. About two thirds of copper and zinc are imported.

Table 8. Reserves and production in 1988: vanadium and mercury

Percentages in world total

Country	Reserves	Production
(I) VANADIUM		
Australia	0.8	-
South Africa	20.2	52.1
USA	3.2	2.9
China	14.1	14.4
USSR	61.7	30.6
	100.0	100.0
(ii) MERCURY		
Spain	61.7	24.2
Turkey	2.8	1.6
USA	2.8	6.2
Yugoslavia	9.8	1.1
Algeria	1.7	11.3
Mexico	4.2	1.7
China	8.4	11.3
USSR	8.4	37.8
Czechoslovakia	0.1	2.6
Others	0.1	2.2
		100.0

Source: Crowson 1990.

The import dependence of Finland may differ from that of the EC-12 in view of the Finnish production of certain metals (lead, copper, zinc, nickel, silver, cadmium, mercury, chromium etc.) but it nevertheless remains valid to say that Finnish industry also depends to a large extent (for certain metals entirely, for other partially) on imports.

The high dependence on supplies form abroad and overseas brings to the fore the similarly high concentration of reserves - and indeed production - of many metals. As table 7 indicates, in the case of 26 minerals more than 30 % of world reserves are concentrated in one country; in thirteen cases this concentration ratio is 50 % or more and in six cases it exceeds 70 %. Actual production is also highly concentrated, though not always parallel with the concentration of reserves - as shown in table 8 on the examples of vanadium and mercury.

There can be many reasons for a possible interruption of normal supplies: natural disasters, transport difficulties, local strikes, political upheavals, wars and so forth. If any of these hits a country which is the origin of a large part of supplies - the material in question will unavoidably become scarce. The scarcity is usually of short duration and can often be bridged by normal - or even strategic - stockholding. A more serious situation may arise if for any reason all supplies from any one of those countries become jeopardised where reserves (or production) of several minerals are highly concentrated (in table 7 South Africa is shown to be in this situation six times, the USSR five and China four times). However, since mineral exports constitute a significant source of the producing countries' export earnings it can be assumed that they themselves will do their utmost to overcome supply difficulties within as short a time as possible.

Some specific points for the future

Although difficult to quantify, at least three specific developments are likely to have significant impact on any future scenario. These are: metal needs in the non-industrial areas, minerals from the sea-bed, and new materials. We take these in turn.

Table 9. GDP growth and metal intensity in Japan, China and (South) Korea, 1960-86 [a)]

	Aluminium				Copper				Steel			
	1960	1970	1980	1986	1960	1970	1980	1986	1960	1970	1980	1986
(i) Intensity of metal use, tons per million constant 1980 dollars of GDP												
Japan	0.61	1.35	1.55	1.41	1.23	1.22	1.08	0.93	78.6	103.8	74.6	53.3
China	0.80	1.34	1.92	1.52	0.98	1.07	1.29	0.91	78.4	124.9	149.0	153.6
Korea	a	0.54	1.08	1.95	(b)	0.26	1.35	2.61	12.4	45.1	89.0	111.4
World	0.81	1.18	1.27	1.19	0.93	0.86	0.78	0.72	65.4	69.5	59.7	51.8

(ii) Average annual GDP growth, per cent	1960-70	1970-80	1980-86
Japan	10.5	4.6	3.6
China	4.1	5.5	9.4
Korea	8.5	8.2	8.3
World	5.2	3.6	2.5

Source: Tilton (1989).

a) World data are given for comparison.

b) Very small.

Metal consumption in developing countries has already increased quite appreciably. Tilton (1989) convincingly argues that demand is moving persistently, albeit slowly, toward the developing countries. (Of course, by 2017 some of today's 'developing' countries may become industrialised). From very low beginnings, by 1986 the consumption of the countries now classified as developing rose to one fifth of the world aluminium consumption; the LDC's similar share of the world steel and copper consumption was around 15 %. The increase was particularly strong in the Pacific Rim countries of Asia; in the beginning it was caused by the ascent of Japan and China but "after 1970, Japan's contribution tapers off in aluminium and copper and actually declines in steel" but consumption (in terms of its share in the world) continues to rise sharply in China, Korea, Taiwan and the other smaller Asian Pacific countries. This is only partly due to their economic growth, moving far ahead of that of the world; the main reason was the dramatically growing metal intensity as indicated in table 9.

As one of the explanatory factors of this phenomenon Tilton quotes IISI (1972) and Malenbaum (1973,1978): 'In poor countries, rising income tends to be spent on better housing, automobiles and other metalintensive products, causing the intensity of metal use to rise as development proceeds. As per capita income continues to rise, however, these basic needs increasingly become satiated, and consumer preferences shift toward education, medical care and other services. At some point, further increases in per capita income reduce the intensity of metal use'.

This 'point' has been reached and surpassed by Japan: China and Korea may not have reached it - and other LDC countries may experiencing similar development in their metal usage as they approach this turning point in the future. In other words: their metal requirements could also increase sharply. Thus, although metal intensity in the advanced areas of the world may decline, additional use in the developing world could balance - or more than balance - the possible relative decline. Elasticity calculations, as shown in table 10, strongly support the above statements.

Table 10. Elasticity of demand for NF metals[a)]

	OECD	Centrally planning countries	Developing countries
Aluminium	0.03	0.44	1.47
Lead	b)	0.24	0.78
Copper	-0.83	0.44	1.18
Zinc	-1.67	0.42	1.18
Tin	-3.52	0.27	0.04
Nickel	-0.83	0.51	1.87

Source: Metallstatistik, Metallgesellschaft, Frankfurt a/M, Monthly Bulletin of Statistics, UN, New York.

a) Per cent changes in metal consumption for one per cent output change in manufacturing in the period 1973-1983.

b) Abnormal values.

At the moment it may sound like science fiction but on a 25-year horizon the mining from the sea-bed may be nearer to reality. It would mean an unconventional addition to resources. The position, in the briefest terms[1] can be summed up as follows.

It has been known for some time that various minerals exist on the deep sea-bed of oceans, some with metal content. They take the form of nodules. In view of their high manganese content they have come to be called manganese nodules; this, in fact, if imprecise because the nodules are polymetallic, containing a number of metals, such as cobalt, nickel, copper and at least another ten other metals in varying fractional quantities. These nodules are known to occur throughout the world's oceans but the deposits believed to be the most promising in terms of technical and economic viability of recovery and processing are probably those in the Pacific Ocean. Geologists and scientist cautiously expressed the view that a typical nodule sample from the best potential of the Pacific potentially contains approximately 27-28 % mangaense, 1 1/4 - 1 1/2 % nickel, 1 - 1 1/4 copper and 1/4 - 1/2 % cobalt. The composition can vary a great deal: another sample from the Atlantic contained 24 % manganese, 14 % iron and other metals in smaller quantities.

All these estimates are of course rather hypothetical; so are some others indicating that potential production from just one properly organised sea-bed mine site of considerable size may be able to satisfy some 15 % of the world present requirements of cobalt (in 1986, world cobalt production was only 36 thousand tonnes). Much smaller shares of the present global requirements for other metals would be covered on the same basis: some 5 % of nickel, 3 % of manganese and about 1/4 % of copper (1986 world production was 3/4 mn tonnes of nickel, 8 1/2 mn tonnes each of manganese and copper).

This, however, is for one major site only. If the first pioneering enterprise succeeds, it may be followed by others and seabed mining could become a source of supplies of some importance. This is unlikely to happen soon. The legal framework has already been created by the passing of the Law of the Sea, promulgated in 1982 by a convention of the United Nations (signed by some 120 states). But because of the unusual pioneering nature of the scheme, the engineering and other technical problems to be solved, and - last but not least - the doubtful return on the huge capital required for this kind of investment - sea-bed mining so far has not started on any commercial scale. Nevertheless: it is a factor that, although bordering on the impossible at present, may become of some significance in the more remote future.

One additional point deserves mention. According to some geologists' view, resources of the four main metals in the nodules on the seabed may exceed already known land-based reserves and - which is the important point - they are being formed continuously on the ocean floor, as the result of chemical actions and reactions in the seawater. If it is then further assumed that the metal content of the newly formed nodules is comparable with those already analyzed, the metals contained in them could be considered as renewable natural resources. This theory, if correct, would throw new light on metal resources which so far have always been treated as non-renewable.

Progress in science and technology is continuous - and the sphere of materials is not exempt, as witnessed by the growing body of literature on new and advanced materials (OECD 1990, Forester, 1988), the mushrooming government programmes promoting research and development in this field and other relevant indicators. Among the latter we mention just two:

1) For more details, see UN 1986 and Ray 1988.

- The number of researchers working on materials in Swedish technical universities and cooperative research institutes was 189 in 1970 (of whom 35 were PhDs); by 1985 the total number grew to 402 (115 with PhDs) (OECD 1990, p. 82)

- In 1977/8 altogether 245 diplomas in ceramics alone were granted in the US (BS, MS and PhD); by 1984/5 their number more than doubled to 527 (OECD 1990, p. 63).

The outcome of all this is a long list of new and/or advanced materials. Are they competing with the 'old', traditional materials, particularly metals? There is no simple answer to this question because the newcomers may affect conventional usage in a number of ways. They can simply replace the traditional material; they may be applied in some other way such as coatings or alloys, complementing or improving the 'old' metals' properties, adding to their usefulness and applicability and maybe even expanding the area of their use; and they may also create entirely new fields of application.

One example: micro-alloyed steel utilizes small concentrations of special alloying elements, such as niobium, vanadium or titanium, with the result of highly improved properties of steel. Micro-alloyed steel can be used in many critical applications where steel 'as before' might not have been the most advisable material to apply (e.g. pipelines, pressure vessels, oilrigs etc). The strength levels achieved are two or three times greater than with mild steel, with high resistance to fracture and easy welding; all this has permitted major new developments in design and fabrication. These highly alloyed steel compositions are expensive, yet they are increasingly applied where the extra properties are required.

There is an extensive range of alloyed steel compositions; many of them tailored to specific environment - for example, to resist a particular type of corrosion. But the advance is not restricted to steel: it affects all metals and many other materials.

New materials create new markets. Most apparent this has become in the electronics industry where semiconductor silicon devices have become dominant; growing demand for them led to the development of synthetic quartz crystals.

Some 'new' materials can in fact be very old, but they are new in some applications. Ceramics were known in ancient times, but it is only in the most recent years that ceramics have been developed to be use in high-temperature engineering applications. A further development was the combination of silicon, aluminium, oxygen and nitrogen into a new material called 'Sialon' with extremely high strength at very high temperature combined with toughness and wear resistance, making it ideal for engine components, cutting tools etc.

To increase resistance to wear has for long been an aim in materials research. New methods of coating proved the most promising departure. The coating of metals by plastics was already a step forward; but more modern methods apply unusual materials for this purpose as well as new techniques (such as e.g. vapour deposition) to form extremely thin layers on the base metal. This doubles or trebles the wear resistance; more complex processes can lengthen a tool's life by a factor up to 10.

In the above only some of the new materials or combinations have been specifically mentioned. It is not our aim here to give a complete list - it would be changing anyway during the next quarter-century - that would include, among others, engineering thermoplastics and duroplastics, various composites, structural and other ceramics, new glass-based products and optoelectronics (including glass fibres), and superconductors.

Many of these are well advanced and have already been used commercially; others may be the well-guarded secrets of the developers; and again others may come in the next century. Their widespread use, however, depends on a number of factors, such as availability, price, properties and the ease of processing or application. The combination of these factors is not easy to achieve.

For example, carbon fibres, usually encased in plastics, could replace many metals because of outstanding properties. They were first commercially applied in the narrow area of sports goods - golf shafts, tennis rackets and fishing rods. Processing was slow, the quantity required small, hence the price remained high - and carbon fibres did not look a commercial proposition. Only later on, and even then rather slowly, did the new material penetrate the aerospace and other industries. Thus carbon fibre's difficulties were not dissimilar to the experience of aluminium, a new metal hundred years earlier. (See pp 9-10 above)

There is strong ongoing research and development in all areas of materials sciences and further advances are very likely. There is, however, another aspect that must be remembered: new manufacturing technologies. Again, these are difficult to foresee over our long horizon but there are a few already at some stage of development (even dissemination) and are likely to be widespread early in the next century; among them are:

- powder metallurgy, which is supposed to avoid the time-consuming and wasteful conventional shaping of parts and components;
- precision casting; this has become imperative in modern aerospace and a few other industries but is still probably at the early stage of its possibilities;
- superplastic forming and diffusion bonding which reduce several operations into one single process;
- CAD/CAM techniques: at the moment these are applied on a limited scale by the most advanced companies but will spread over a much wider field and, particularly when combined with robotics or flexible manufacturing systems, raise special requirements of material properties;
- coating technologies which still have to go much further in surface treatment methods;
- the application of lasers to welding and other forms of joining materials.

These new processes will certainly have an impact on the search for materials that suit them best.

RENEWABLE MATERIALS

The case of renewable materials is - by definition - simpler albeit not without uncertainties. Agriculture and forestry are the producers of these materials; the main commodity groups among them are textile fibres, natural rubber and wood. One common characteristic of these commodities is the existence of substitutes; these latter can perfectly replace the natural product is certain end-uses, not entirely satisfactorily or not at all in others. Often the mixture of the natural and the man-made product has been widely accepted and even preferred (e.g. in the textile area) whilst elsewhere the natural product remained not only dominating but indispensable, such as timber in many applications or woodpulp for papermaking.

Another common characteristic of renewable materials is that the chief factor for their production, land, is the resource that cannot be expanded, it is finite. The production of industrial materials of agricultural origin compete with food production on the land available for agricultural use, whilst the latter has for a very long time been under pressure from other land-users, such as urban - and in general: human - settlements, industry and transport, to name just the major ones.

Between 1800 and 1950 the world's population increased by a factor of 2.6; but over the same period the number of persons living in settlements of 20.000 or more rose by a factor of 23, and the populations of large cities with 100.000 or more inhabitants by a factor of 35! And the agglomerations increased: by now one fifth or even one quarter of many countries' population lives in and around the capital cities in Europe and also elsewhere. (Hall, 1977) In 1955, 55 % of the West European population was classified as 'urban'; by 1980 this share had grown to 70 % and the trend is expected to continue.

This tendency to urbanisation has meant the encroachment into agricultural land around the growth points (which are not restricted to capital cities). More and more land was required for industrial purposes and modern transportation also makes demand on the land: airports, motorways and improved other roads have occupied land previously used for other purposes in the same way as the railways did in the 19th century and even later. The combined consequence is that areas of land available for other purposes - mainly agriculture but also forestry and recreation - have been gradually contracting.

It is difficult to foresee what the future will bring. According to UN estimates and forecasts, the number of urban areas with more than 5 million inhabitants (!) rose from 20 in 1970 to 30 in 1985 and expected to jump to 48 by the year 2000. (But of this growth of altogether 28, there are only 2 in the developed and 26 in the developing countries including China). (UN 1987). Although the decline of the old 'smokestack' industries may 'free' some land, this will probably be more than balanced by transport's new requirements. Thus the outlook is not particularly rosy and there seems to be even greater need to manage land use - by means of more forceful land and town planning and stricter regulations for preserving 'green' areas - than in the past.

In this context let us quote an expert report (Brookings, 1974) according to which:

> "Large additional amounts of land in the world could be brought under cultivation. Recent studies (by the UN Food and Agriculture Organization, the US Department of Agriculture, and Iowa State University) have come to essentially the same conclusion: at least twice as much land as is now being used is suitable for crop production. ... Whether these possibilities will be exploited in future will depend primarily on the costs of doing so as compared with the costs of achieving higher yield per acre." (p. 21)

This and similar statements always concern first and foremost food supplies but they are obviously relevant to the production of industrial materials as well. Moreover, if the statement was true in 1974, it must be - at least to an extent - true today.

Despite the encroachment of various activities into the land area of agriculture, production has kept pace with growing requirements through the ages. This was due to a number of factors. First, the area of cultivation could be increased in past centuries, partly by simply extending activity to new, hitherto unpopulated areas (e.g. to central and Western parts of the US) and partly by uprooting forests. Secondly, by upgrading agricultural land (e.g. from grazing to grain production). Thirdly, converting deserts or semi-deserts into useful agricultural land by means of irrigation (e.g. in Israel - although similar attempts elsewhere have led to ecological disaster as around the Aral Sea). Fourthly and mainly, by increasing productivity, as a result of improved methods of cultivation, plant protection, the use of fertilizers - all combined to raise the yield per unit of land. New varieties of plants had been introduced with higher yield and the development of animal husbandry through the ages had been similar.

This type of change is nowhere near its end; progress in this direction will continue, but production should grow simply by means of the dissemination and further spread of best practice techniques. This hope finds its basis in the varying degree of the present crop results. It can be demonstrated on the example of the perhaps most important agricultural industrial material: cotton. Table 11 indicates the average yield of cotton in major geographical areas and also the countries with the highest and lowest yields within the same areas. The differences are staggering. Naturally, climatic conditions are different and account for a good deal of the variations, but even within comparable climates the differences in yield appear very great.

Table 11. Cotton: indicators of yield, 1989/90

Kg/hectare per year

Area	Average kg/ha	Highest yield	Lowest yield
North America	701	Mexico 895, USA 694	Cuba 269, Dominican Rep. 167
Central America	828	Guatemala 977	El Salvador 609
South America	397	Peru 623	Brazil 319
Africa: North	592	Egypt 673	Sudan 469
'Francophone'	432	Madagascar 714	Central Afr. Rep. 198
Other	222	Uganda 800	Tanzania 85, Zaire 93
Europe: West	917	Spain 1003	Italy 500
East and USSR	796	USSR 800	Albania, Yugoslavia 269
Asia/Oceanic			
East	755	China 755	Taiwan 381
South-East	1027	Australia 1321	Vietnam 104, Indonesia 127
South	337	Pakistan 534	Burma 70, Bangladesh 220,
	773		India 273
Near East	535	Israel 1484	Iraq 287
World average		..	..

Cotton: World statistics April 1990, International Cotton Advisory Committee, Washington.

It is reasonable to assume that it is depending on time - and it may take quite a long time - when higher-yielding varieties and better methods of cultivation are introduced in countries with poorer crop than could be achieved.

Perhaps it is also worth remembering that in several years during the last decade considerable parts of the area usually under cotton in the USA - one of the largest producer and exporter of cotton - were taken out of production in order to avoid or reduce world overproduction.

Another important material is natural rubber whose replacement started during the 1939-45 World War in a major way (Table 12); by now some 70 % of the world's elastomer requirements are covered by synthetic rubber. The difference in its use is still great between the developed and the developing countries (Table 13) and, again, it is reasonable to assume that with the progress of their technology the latter will take over advanced industrial practices favouring the synthetic product. It is worth noting, moreover, that under the pressure of synthetic competition significant advance had been achieved in the production of natural rubber, particularly in Malaysia, where the productivity of rubber plantations was more than doubled since the war, as a result of introducing new techniques of various kind.

Summing up, it does not seem likely that lack of supply of industrial materials produced by agriculture would cause any unsurmountable trouble in the foreseeable future. There are distinct possibilities to raise their production (barring, of course, environmental disaster) and, if it came to the worst, man-made materials have already gone a long way to replace them.

Forestry products belong to a somewhat different category, however, for two main reasons. First, because the reproduction of forests take a long time, several decades despite undeniable progress in this direction; and secondly, because of continuous deforestation: several million hectares of tropical forests are lost every year and there are observers who consider this one of the most serious single phenomenon that eventually may lead to environmental catastrophe.

Table 12. Natural rubber's share in total elastomer consumption
Per cent in total, 1988/9

Developing countries . .	57.5
Developed countries . . .	26.2

Source: Commodity review, UN/FAO, Rome, 1989.

Table 13. Natural and synthetic rubber consumption, 1940-82
Per cent shares in world total

	1940	1955	1979	1982
Natural	97	56	29	30
Synthetic	3	44	71	70

Source: Roze, 1988.

While 'acid rain' threatens forests in some temperate areas it is the tropical belt that suffers most by deforestation, because forests regulate climate, provides catchment protection, and its gradual loss prevents effective soil erosion control and has many other ecological effects, apart of course from reducing available supplies in the future.

According to various estimates (WRI, 1986, UN/FAO, 1989) around 3 billion m^3 wood is being harvested annually in the world - about 55 % hardwood and 45 % softwood. Some one half of this is roundwood in the tropical areas. FAO estimated that in the developing countries 80 % of the wood consumed is used as fuelwood, in stark contrast to the advanced countries where only 18 % is fuelwood and 82 % goes into various industrial (including building and construction) end-uses. Thus, as and when it comes to a more serious shortage the first and worst hit will be the developing countries, unless something else begins to replace fuelwood as a source of energy.

The future fate of the world's forests has often been discussed by many; estimates vary wildly. Clawson (1981) in her critique of the 'Global 2000' report presented to President Carter ("Global Future: Time to Act") simply puts it: "The forestry picture is one of the gloomiest of the whole report", in assuming that deforestation would continue at the rate of 18-20 million hectares per year through the end of the century. She also cites another, more optimistic projection (by FAO authors) expecting an annual deforestation of 'only' 4 mn hectares.

In view of this discord it seems advisable to go into some details of the facts. In the fifteen years to 1986 the forestry area of the world decreased by 122 million hectares or nearly 3 %. The reduction hit every continent except Europe (and perhaps the USSR), but not equally: it was the most severe in Africa and South America (Table 14). In the countries with the largest forest areas deforestation in the first half of the 1980s was nil or negligible (Table 15) with the exception of Indonesia and Brazil. (It has been widely reported that in the second half of the last decade deforestation in Brazil, particularly in Amazonia, increased significantly; it should be remembered that the deforestation of 1 % of the area in Brazil alone means a loss of 4 million hectares!)

Table 14. Forestry indicators, 1971 and 1986

Geographical area	Forest area[a] 1971	Forest area[a] 1986	1971-86 change mn ha	1971-86 change %	Forests as % of total area b 1971	Forests as % of total area b 1986	Distribution of forests,% (world=100)
World	4200	4078	-122	-2.9	31.4	30.5	100
Africa	735	689	-46	-6.3	24.2	22.7	16.9
North & Central America	697	685	-12	-1.7	31.1	30.6	16.8
South America	964	909	-55	-5.7	54.1	51.0	22.2
Asia	551	540	-11	-2.0	20.0	19.6	13.2
Europe excl.USSR*	151	156	+5	+3.3	31.0	32.0	3.8
USSR [c]	914	943	+29	+3.2	40.8	42.1	23.1
Oceania[d]	188	156	-32	-17.0	22.1	18.3	3.8
* for comparison:							
Western Europe	122	126	+4	+3.3	31.7	32.7	3.1
Eastern Europe	29	30	+1	+3.4	28.4	29.4	0.7
Finland	22.5	23.2	+0.7	+3.1	66.8	68.8	0.6

Source: Production statistics, 1987. UN/FAO, Rome, 1988.

a) Million hectares.

b) The total area includes inland water.

c) FAO estimates.

d) Includes Australia.

Table 15. Forestry: selected indicators for countries with the largest forest areas and for Nordic countries

Country:	Area (000 hectares)[a] of: open [b] forests	Area (000 hectares)[a] of: closed [c] forests	Deforestation of closed forests [d]: 000 ha per year	Deforestation of closed forests [d]: % of area	Reforestation 000 ha [d] per year	Managed closed forests [a] [e]: 000 ha	Managed closed forests [a] [e]: % of area
(i) Countries with the largest forest areas:							
USSR	137.000	791.600	-	-	4540	791.600[f]	100[f]
Brazil	157.000	396.030	1480	0.4	346	na	
Canada	172.300	264.100	-	-	720	na	
USA	102.820	195.256	-	-	1775	102.362	52
China	450.000	125.000	-	-	4552	na	
Indonesia	3.000	123.235	600	0.5	187	32.557	26
(ii) Nordic countries							
Finland	3.340	19.885	-	-	158	10.578	53
Norway	1.066	7.635	-	-	79	1.130	15
Sweden	3.442	24.400	-	-	207	14.301	59

Source: WRI, 1986, p. 274.

a) 1980.
b) Open forests: trees covering at least 10 % of ground.
c) Closed forests: trees fully shade the ground.
d) Data concern 1980-1985.
e) 'Management' here means the active management of forest growth and regeneration in accordance with a plan, including logging control, fire and disease preventation and treatment and silvicultural research.
f) Data doubtful.

Table 16 gives a list of the countries with high degree of deforestation; it is worth noting that a) all of them are developing countries; b) most of them relatively poor and some among the poorest; c) all of them tropical or subtropical countries; and d) in 15 countries the rate of deforestation is alarmingly high: over 2 % and in three cases (Ivory Coast, Nigeria and Paraguay) in excess of 4 % a year.

In all these countries there is, and there will be, a problem because not only the need for fuelwood will persist but also the food supply for the growing population puts pressure on the dwindling forest area. In the temperate zones, particularly in North America and Europe, stability of forested area has been achieved. Admittedly, even here the present situation follows a long earlier period of intensive exploitation and destruction (of which the disappearance of the once proverbial English forests is one good example), but this demonstrates the lack of inevitability in extrapolating deforestation trends. How, when and to what extent the European and North American experience and practice can be transferred to other, chiefly the tropical, zones of the earth - remains an open question. Thus, forest products will probably remain a problem area for a long time to come.

Table 16. Countries with high degree of deforestation

In per cent of deforestation of forest area, per year in 1980-5

	1/2 to 1 %	1 to 2 %	2 to 3 %	3 and over (with % given)
Africa	Ghana Kenya Mozambique Rwanda Sierra Leone Togo	Angola Guinea Madagascar Uganda Zambia	Benin Gambia Guinea-Bissau Liberia	Ivory Coast 5.9 Nigeria 4.0
Americas	Dominican Rep. Panama	Guatemala Jamaica Mexico Colombia	El Salvador Honduras Nicaragua Ecuador	Costa Rica 3.9 Haiti 3.1 Paraguay 4.6
Asia	Indonesia Philippines Vietnam	Laos Malaysia	Sri Lanka Thailand	

Source: WRI, 1986, p. 274.

Nevertheless, we agree with Sedjo and Clawson (1984) who after having studied the topic extremely thoroughly, concluded by saying that

- "there is little possibility of the world running out of forests" but there appear to be excessive rates of deforestation in certain regions, particularly in the tropics;
- the supply of wood will be adequate in the foreseeable future; there will be problems (particularly environmental) but not of insurmountable or critical nature;
- but within this relatively comfortable overall situation the local and regional situation is much less happy: local wood supply is already inadequate in some regions and the prospects for improvement are not good, for ecological and/or sociological reasons;
- the threat - apart from supply scarcity - is environmental, primarily to water and soil quality and, again, it is local and not global; it is not impossible - though difficult - to avoid or prevent them by different and better management.

Thus, although overall scarcity may be avoided, the local problems may still be present in another 25 years even if - assuming the international will to solve them - the solution may be nearer.

WATER

Freshwater, once freely available in most parts of the world except the arid desert areas, has more recently given rise to anxiety. Two citations should serve for demonstrating the problem:

A recent study of the world's water situation illustrated the origin of water problems as follows:

> "Ancient Romans had access to roughly the same amount of water as the modern Romans do. The critical difference is population: in 100 AD Rome had a population of 1 million, while today it is closer to 4 million". (WRI 1986, p. 121).

In the leading article of Resources (no 83, spring 1986) it says:

> "Nature has endowed the US with prodigious amounts of fresh water. Excepting Alaska and Hawaii, the nation averages thirty inches of precipitation each year, or some 4200 billion gallons every day. Lakes and streams are many, and vast underground aquifers contain thousands of trillions of gallons. Yet, despite the boggling numbers, demand is crowding supply from New York to California, and an arsenal of contaminants threatens to place some water off limits for the indefinite future. Americans once saw clean and inexpensive water as a kind of national entitlement; the resource, it seemed, was all but inexhaustible. Now water has become relatively scarce, both absolutely and economically, and conflicts among its users are common". (P.1.)

This latter view comes from the USA, the country relatively waterrich - among the best endowed in the world. Many other countries are much poorer in water, some with a water availability of a small fraction of the US (Table 17). There are chronic shortages in sub-Saharan Africa and the Middle East, but also in parts of major countries which otherwise, in general terms appear to be fairly well provided for, such as e.g. the USA, Australia and the USSR.

The problem is twofold: quantity and quality.

In the forty years 1940 to 1980, total water use increased from 900 to 3600 km^3 - fourfold; in the same period global water usage per capita doubled. (WRI 1986 p. 129). The pattern of water usage varies greatly by country but the bulk, well over one half of all water (worldwide) is being used for irrigation, most of the rest for industrial purposes and only somewhat less than one tenth, for public use, drinking water and sanitation.

Table 17. Water availability in selected countries

<u>Per capita:</u> thousand m^3/year

Water-rich countries		Water-poor countries	
Canada	121.93	China	2.52
Malaysia	29.32	India	2.43
Sweden	22.11	Peru	2.03
Finland	21.33	Poland	1.57
Austria	12.02	Egypt	1.20
USA	10.43	Kenya	0.72

Source: WRI, 1986, p. 123.

Table 18. The water economy of England and Wales, 1977 and 1987

Megalitres per day

	1977	1987	% change	% distribution
Total water abstracted [a)]	35367	33970	-4	100
Used by:				
Agriculture	235	222	-6	0.7
Power stations [a)]	13406	12806 [a)]	-4 1/2	37.7 [a]
Industry [b)]	6958	3702	-47	10.9
Public water supply [c)]	14768	17240	+17	50.7

Source: Digest of environmental protection and water, HMSO, 1989.

a) Excludes tidal water but includes water used for hydropower (about 5600 megalitres/ day in 1987).

b) Excluding electricity.

c) Piped mains water (chiefly household consumption but including other minor uses as well).

Where water is scarce the shortage hits all three main channels of use. The situation is worst in many of the developing countries where the supply of population with safe drinking water is unsolved, partly because of the shortcomings of the distributive network but mainly in view of the general shortage. In some areas - in the least developed countries - not more than about one third of the population enjoys safe drinking water, and in the rural areas this proportion is even less. In the very populous South and East Asia not more than one half of the population is provided for safe drinking water (Table 18).

The utility of water for human use is a permanent worry in the advanced countries as well, in view of the pollution caused by all the chemical and other substances emptied into the waters of rivers and coastal seas by industrial and agricultural activities. In advanced countries there is a permanent fight for neutralising them and thus improving the quality, and also for recycling the water, helping the quantity. Technology for all this exists - though it still is far from comprehensive or perfect - but is expensive and therefore not widely enough applied even in the advanced rich countries; for many developing countries the cost may be prohibitive.

Changes in the pattern of national output and of industry can reduce global water needs - though at the moment such possibilities are rather restricted to the industrial countries - as can be shown on the example of England and Wales, where in the ten years to 1987 total water abstraction was reduced by 4 % (Table 18).

In some respects this may not be a typical example because of the minimal degree of irrigation; but industrial use was reduced by almost one half in these ten years, and water requirements of the power stations also decreased somewhat, as the result of the reduced activity of some major water-hungry branches of industry, better water management and forced recycling of the water (which often requires treatment for cleansing). But even here, the water saving indicated by global data conceals the significant increase of the quantities required for public supply: 17 % over ten years, or 1.6 % a year. In England and Wales, public supply accounts for one half of all water needs; in other countries this proportion may be considerably smaller - but its continued increase is very likely everywhere.

Table 19. The supply of population with safe drinking water in developing countries, 1985 and 2000 [a)]

Area	Number of countries	Population million 1985	1985 % [b)]			2000 [c)] total
			urban	rural	total [d)]	
North Africa	3	51	94	39	64	70
Sub-Saharan Africa	34	345	76	24	36	37
South and East Asia	13	1366	69	46	52	58
West Asia and Mediterranean	4	32	100	72	92	94
Western Hemisphere	23	389	86	45	74	77
Total, developing countries as above	77	2182	78	42	54	58
of which: least developed countries	25	308	51	34	36	37

Source: UN 1988

a) The percentages are rounded.
b) Actual.
c) As estimated by the UN World Health Organisation in May 1988.
d) Country group figures are averages of individual country percentages weighted by urban, rural or total population.

Given all these facts - what is the future for freshwater supplies? Local difficulties - particularly in the developing countries - will persist and the population pressure may make it even more delicate to ease them. As Table 19 indicates, only very gradual and rather marginal improvement is expected between now and the end of the century. In the advanced countries the situation is better; some of them are well provided for water supply but apart from these water-rich countries the supply position may worsen in the next twenty five years. It will be a general requirement to devote much more attention and resources to the quality of water, apart from the quantity. It will be unavoidable to greatly improve water management, to introduce water-efficient technologies in industry and agriculture, to raise irrigation efficiency by reducing over-irrigation and transportation loss.

All this assumes no major impact of climatic changes (man-made or otherwise) and no more than marginal materialisation of the various threats to the environment.[1)]

As the last resort there is of course one way out: desalination of seawater, of which the supply is literally limitless. But it is costly and requires large quantities of energy; in some areas of the world solar energy may suffice but elsewhere any such solution would add to the world's energy problems.

CONCLUSIONS

The conclusions that emerge from this wide ranging survey can best be summed up as follows:

+ In general, there are sufficient reserves of non-renewable materials - minerals and metals - to satisfy foreseeable demand between now and the 'centenary year' of 2017. Towards the end of this period there may be shortages which will probably be overcome by means of substitution or technological change - but this is unlikely to affect more than a very small number of minerals. For the bulk of these materials even the reserves as recorded now appear adequate for much longer periods.
+ Renewable materials similarly do not give a ground for particular worry, with the notable exception of forest products; the future supply situation of the latter appears more precarious, partly because environmental damage.
+ Water supply is less promising: it will require careful management; eventually, energy-hungry desalination of seawater could solve this problem though this may not be necessary earlier than after the period covered.
+ Temporary difficulties cannot be ruled out; they may affect particular materials and/or specific producing areas. But they are likely to be short-lived.
+ Finally, although the past is not necessarily a foolproof guide for the future, the past development of scientific and technological advance makes it reasonable to assume that progress will continue and therefore if any, at present unforeseen, scarcity of some material may occur ways and means will be found for overcoming or bypassing it.

1) These are briefly sketched in Appendix I; naturally, they may have an impact not only to water supplies but also affect those of industrial materials of agricultural origin and - to an extent - even mining.

Appendix I

Threats to the environment

A special supplement to the December 1988 issue (Vol. 174, no 6) of the National Geographic magazine pinpointed the main threats to the environment. These are listed below:

population pressure
air pollution
ozone concerns
acid rain
water pollution
water diversion
toxic wastes
radiation perils
species extinction
fisheries depletion
deforestation
desertification

The impact of most of these is clear (for example, the effect of acid rain on forests). The combined result of some of those listed is the so-called greenhouse effect.

The atmosphere of the earth allows much of the sun's radiation to pass through, warming up both the atmosphere and the land and sea. The infrared radiation given off by the warmed earth is partly passed back to the atmosphere, but some of it is re-emitted back to earth. The atmospheric blanket of gases surrounding this planet keeps it some 30°C warmer than it would otherwise be.

Carbondioxide (CO_2) and water vapour have always played a part in this natural process. But now it seems that industrial activity, intensive agriculture, the burning of fossil fuels and deforestation are increasing the CO_2 concentration int he atmosphere (together with other gases), thereby intensifying this 'greenhouse' effect. It is the additional warming that seems to cause trouble.

The 'greenhouse' cocktail' in fact consists in fact not only of CO_2 although that accounts for about one half of it. Other gases playing part in it are CFC, methane, nitrous oxide and ozone.

The earth has certainly cooled and warmed before as cold ('ice') ages have come and gone. Climatic records show that since the middle of the last century there has been a gradual temperature increase. It is now widely thought (but disbelieved by some climatologists and other scientists) that by the year 2030 greenhouse gas levels will be twice what they were before the industrial revolution - and this could eventually lead to a global warming of between 1 1/2 and 4 1/2 °C.

Whilst this may not appear very much at first sight, it is in fact very significant considering that the world is only 4°C warmer now than during the last ice age many thousand years ago. It could have dramatic effects indeed:

- sea levels may increase, caused by melting ice and thermal expansion; it can cause flooding in low-lying countries such as the Netherlands, Bangladesh or parts of East Anglia;
- regional shifts may occur in climate and disruption of weather patterns with the likelihood of more frequent floods and droughts;

- very serious effects on crops in some countries and areas; elsewhere, higher average temperatures and rainfall could increase yields but mild winters could also make pest control more of a problem.

(Comments on the greenhouse effect are based on the article 'Words of Warming, in 'Which', April 1990.)

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