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GREEN economy

Manufacturing

Investing in energy and resource efficiency

Acknowledgements

Chapter Coordinating Authors: **Robert Ayres**, Professor Emeritus, INSEAD, France and **Cornis van der Lugt**, Resource Efficiency Coordinator, United Nations Environment Programme (UNEP).

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Key messages

1. As currently configured, manufacturing has a large material impact on economy and the environment. Manufacturing is responsible for around 35 per cent of the global electricity use, over 20 per cent of CO_2 emissions and over a quarter of primary resource extraction. Along with extractive industries and construction, manufacturing currently accounts for 23 per cent of global employment. It also accounts for up to 17 per cent of air pollution-related health damages. Gross air pollution damages are equivalent to between 1 and 5 per cent of global GDP. This cost of air pollution-control policies is projected to increase in a business-as-usual scenario by a factor of three by 2030.

2. Key resource scarcities – including limited recoverable oil reserves, metal ores and water – will challenge the sector. As industries resort to lower-grade ores, more energy is required to extract useful metal content. Improved recovery and recycling will increasingly become a decisive factor for both economic performance and environmental sustainability. The same applies to water use by industry, which is expected to grow to over 20 per cent of global total demand by 2030.

3. Win-win opportunities exist, if manufacturing industries pursue life-cycle approaches and introduce resource efficiency and productivity improvements to get more useful output from resource inputs. This requires supply and demand-side approaches, ranging from the re-design of products and systems to cleaner technologies and closed-cycle manufacturing. If the life of all manufactured products were to be extended by 10 per cent, for example, the volume of resources extracted could be cut by a similar amount.

4. Key components of a supply-side strategy include remanufacturing – for example of vehicle components – and the recycling of heat waste through combined heat and power installations. Closed-cycle manufacturing extends the life-span of manufactured goods and reduces the need for virgin materials. Repair, reconditioning, remanufacturing and recycling are fairly labour-intensive activities, requiring relatively little capital investment. Remanufacturing operations worldwide save about 10.7 million barrels of oil each year, or an amount of electricity equal to that generated by five nuclear power plants.

5. While direct job effects of greening manufacturing may be neutral or small, the indirect effects are significantly higher. Manufacturing has become increasingly automated and efficient, which has been accompanied by job losses. This can be countered by life-cycle approaches and secondary production, for example in the form of recycling, to secure jobs, for which safe and decent working conditions are of paramount importance.

6. Green-investment-scenario modelling for manufacturing suggests considerable improvements in energy efficiency can be achieved. By 2050, projections indicate that industry can practically "decouple" energy use from economic growth, particularly in the most energy-intensive industries. Green investment will also increase employment in the sector. Tracking progress will require governments to collect improved data on industrial resource efficiency.

7. Innovation needs to be accompanied by regulatory reform, new policies and economic instruments to enable energy and broader resource-efficiency improvements. Environment-related levies, including carbon taxes, will be required to ensure producers include the cost of externalities into their pricing calculations. Governments are challenged to find mixes of policies and regulatory mechanisms that best suit national circumstances. In particular, developing countries have a strong potential to leapfrog inefficient technologies by adopting cleaner production programmes, particularly those that support smaller companies, many of which serve global value chains. Of special importance to manufacturing is the introduction of recognised standards and labels, backed by reliable methodologies.

1 Introduction

Manufactured products are a key component of human consumption, whether as finished or semi-finished goods. Manufacturing processes are a key stage in the life-cycle of material use, which begins with natural resource extraction and ends with final disposal. Basic industries such as cement, aluminium, chemical and steel supply the semi-finished, or intermediate goods, used to build houses, cars, and other appliances used in daily life. Other industrial sectors produce finished goods such as clothing, leather, fine chemicals, electrical and electronic products.

In *Our Common Future* (1987), the Brundtland Commission foresaw industrial operations that are more efficient in resource use, generate less pollution and waste, are based on the use of renewable resources, and that minimise irreversible impacts on human health and the environment. This vision became the drive for concepts such as Cleaner Production promoted by UNEP and others since the 1980s. It remains a challenge for manufacturing industries world-wide, highlighting a need for more fundamental change in which the purpose of products and side-effects of manufacturing become a source of inspiration for re-design and beneficial output (Braungart and McDonough 2008).

In order to implement a strategy of sustainable use of natural resources based on integrated resource management and resource efficiency, policy interventions supplemented by voluntary initiatives are needed at each stage of the life-cycle of production and use. The balance between upstream and downstream interventions is up for policy debate. Upstream policy interventions, for example, at the stage of mineral extraction or forest harvesting, to minimise adverse environmental impacts or to charge users appropriately for depletion or appropriation of resource rents would have the effect of raising input prices to manufacturing companies.

Policy interventions targeted at manufacturing companies with the aim of reducing pollution to air and water, safeguarding health from exposure to toxic chemicals, and emitting greenhouse gases can also have the effect of increasing the cost of using resource inputs. These, together with other measures, can be powerful drivers in encouraging manufacturing industries to become more efficient in their use of natural resources and energy. Measures intended to improve the performance of markets for secondary raw materials and to encourage recycling can help further to improve the performance of manufacturing companies in reducing their use of virgin raw materials. These are all building blocks for moving us closer to the vision described in *Our Common Future*.

1.1 Structure of the chapter

The chapter starts with a brief sketch of global manufacturing, its importance to developing economies, an explanation for the choice of branches of manufacturing that are the main focus of the chapter, the environmental pressures associated with them, recent trends in "decoupling" economic growth from those pressures, and a definition of "green manufacturing".

Section 2 describes the costs of failing to implement a strategy of greening manufacture. These relate to excessively rapid depletion of natural resources, which could adversely affect future economic growth, the negative externalities of industrial air pollution and the use of hazardous substances.

Section 3 describes a number of strategic approaches to encourage green manufacturing that involve investment in innovation, cleaner energy technologies, resource efficiency and in a transition to green jobs. This includes a *supply-side strategy* involving the redesign of processes and technologies employed in the major materials-intensive subsectors of the manufacturing sector including *closed-cycle* manufacturing where feasible. It also includes a *demand-side strategy* to change the composition of demand, both from within industry and from end-users.

Section 4 argues that there are many opportunities for investments that can lower costs by using less material, energy and water. At the micro-level this can translate into an increase in profitability if the rate of return on such investment is greater than that of an alternative investment. The section provides numerous examples of green investments highlighting in particular their impacts on energy savings and CO_2 emissions reductions, water savings, and employment creation. However, the process of transition may be slowed by the problem of "lock-in" owing to the capital-intensive nature of many manufacturing processes and long plant lives.

Section 5 presents the results of model-based quantitative analysis done for this study that shows how investing to improve resource efficiency in manufacturing can often be profitable to business and increase employment while reducing environmental pressure. At the macro-level it can mean greater GDP and a higher level of environmental services.

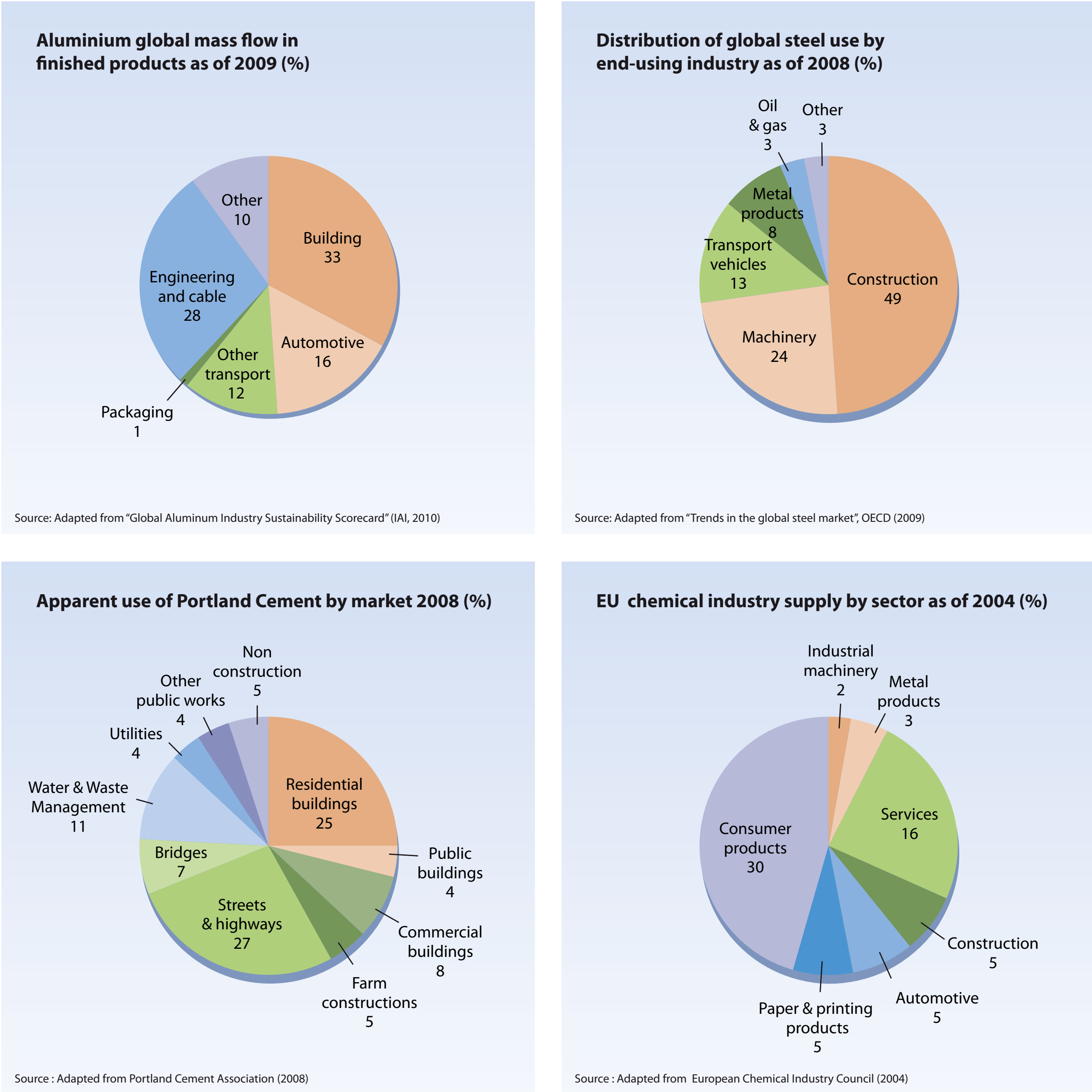

Figure 1: Primary production supplies and their end products

Section 6 discusses the enabling conditions for a green transformation in manufacturing. The various types of policy measures are discussed in some detail. These include regulatory and control mechanisms, economic or market-based instruments; fiscal instruments and incentives; voluntary action, information and capacity building.

1.2 Manufacturing in the global economy

During the 20th century, the growth of manufacturing was phenomenal. World steel production, for example, rose by a factor of six between 1950 and 2000 to over 1.2 billion metric tons (World Steel Association 2009). Aluminium production doubled between 1980 and 2005 (USGS 2009). The growth of industrial production has also been accompanied by increasing pressure on the environment. Industry is responsible for over a third of global electricity use and over a fifth of CO_2 emissions (WRI 2007, IEA 2008).

Manufacturing has been a major driver of overall economic growth of developing countries in the last 15 years. During this period, developing countries' GDP nearly doubled. In 2009, Manufacturing Value Added (MVA) grew by 2.5 per cent while in some major industrial countries it dropped by more than 10 per cent (UNIDO 2010). Following the start of the global financial crisis, a collapse in industrial production in 2009 was drastic in many countries dependent on manufacturing exports. In a front-page article entitled "The collapse of

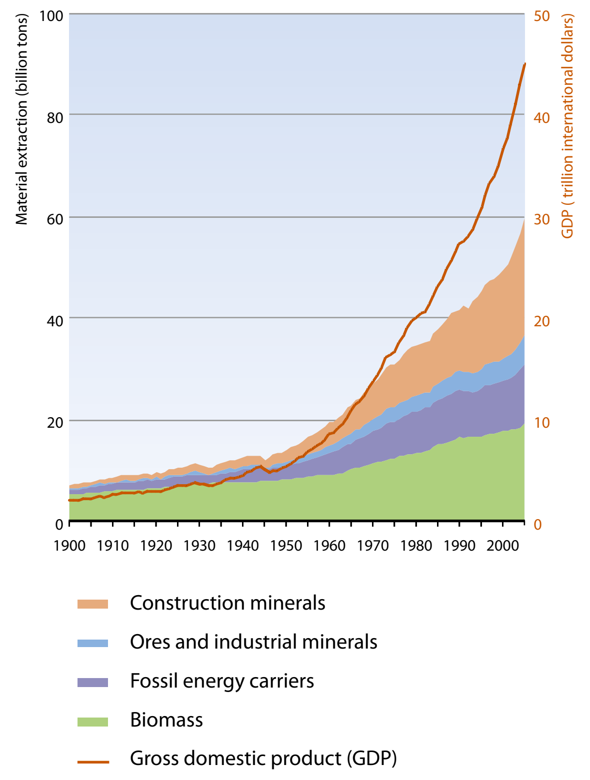

Figure 2: Global material extraction in billion tons, 1900-2005. Industrial production drives most of the ores extraction, and significant parts of biomass and construction

Source: Krausmann et al. (2009)

manufacturing", *The Economist* (19 February 2009) noted the difficulties government programmes, which are often slow to design and amend, face in dealing with the varied, constantly changing difficulties of the world's manufacturing industries.

If anything, the financial crisis highlighted a broader shift in the location of centres of manufacturing that supply global value chains. The contribution of manufacturing to developing world GDP increased to almost 22 per cent by 2009, compared with 18 per cent in 1990 (UNIDO 2010). Industry broadly defined (excluding agriculture and services but including manufacturing, extractive industries and construction) accounted for about 23 per cent of global employment, representing over 660 million jobs in 2009 and has grown by more than 130 million since 1999 (ILO 2011). In manufacturing, the chemical, iron and steel, and paper and pulp industries generate the highest revenues. However, in terms of employment, the textile sector (highly important for LDCs and developing countries) and the basic metals sector (highly important for transition and developed countries) are leading, each accounting for 20-25 per cent of global employment in manufacturing (ILO 2010).

1.3 Scope and definition

This chapter focuses on those manufacturing sub-sectors that are energy-intensive or heavy users of natural resources. It excludes power generation as well as food and refined petroleum products, which are dealt with in the chapters on agriculture and energy. The following manufacturing sub-sectors are given special attention in this chapter:[1]

- Iron and steel (ISIC 241)
- Cement (ISIC 239)
- Chemicals and chemical products (ISIC 20)
- Pulp and paper (ISIC17)
- Aluminium (ISIC 242)
- Textile and leather (ISIC 13 + 15)
- Electrical and electronic products (ISIC 26 + 27)

Figure 1 shows where the products of these manufacturing industries go. The breakdown signals end products such as buildings, vehicles and consumer products that end-users are familiar with from their daily lives. It signals resource intensive consumption clusters related to housing and transport (cf the buildings and transport chapters). This is a reminder of insights from following a value-chain approach, considering green innovations upstream and downstream. Some would say the point of departure for green intervention needs to be design, since most of the business cost of production is determined during the initial design stage. A range of options, upstream and downstream, will be considered in this chapter.

In terms of CO_2 emissions, the branches of manufacturing covered in this chapter account for 22 per cent of global emissions. Emissions from the iron and steel, cement and chemical industries account for most of them, while industries such as textiles and leather can generate significant negative externalities if their effluents are not handled properly. The electrical and electronic goods industries have a crucial role in the global economy, with 18 million jobs (ILO 2007), and account for most of the growth in manufacturing at present. They also have harmful environmental impacts if hazardous chemicals and metals in production and final disposal are not carefully managed.

1. The *International Standard Industrial Classification of All Economic Activities, Revision 4* (United Nations, 2008) (ISIC) divides manufacturing into 24 divisions, which are in turn divided into numerous groups and classes. The activities discussed in this chapter include those found in all or parts of eight of the ISIC divisions. Among the manufacturing industries not discussed explicitly in this chapter are glass, ceramics, wood products, and machinery. This chapter needs to be read in conjunction with the Energy, Buildings, Forests, Waste, and Water chapters.

Historically, GDP has grown more rapidly than material, energy and labour inputs required to produce it. This has been owing to a combination of structural change, as service consumption sectors have grown faster than material consumption, technical change, which, has reduced material and labour inputs (e.g. automation) per unit of production, and more stringent environmental policies, which have driven up the cost of using some pollution-intensive inputs. This resulted, among others, in *relative* "decoupling" of resource input from output and *absolute* decoupling of some of the associated environmental pressures. Yet, resource-efficiency gains have been offset by economic and population growth: overall emissions, energy use and material use continued to grow despite lower emissions, energy and material use per unit output (cf Figure 2). Without *absolute* decoupling, continuous economic growth implies continuously higher energy and resource demands, to levels that put the health of our natural resource base at risk.

The greening of manufacturing is essential to any effort to decouple environmental pressure from economic growth. Green manufacturing differs from conventional manufacturing in that it aims to reduce the amount of natural resources needed to produce finished goods through more energy- and materials-efficient manufacturing processes that also reduce the negative externalities associated with waste and pollution.

2 Challenges – The risks and costs of inaction

The new economic reality for manufacturing industries today include key structural changes such as the globalisation of production with transnational supply and demand, strong economic growth in Asia (notably China) and an increase of raw material prices. The following analysis focuses on the challenges of natural resource scarcity, the external costs of air pollution, as well as risks associated with hazardous substances and waste.

2.1 Natural resource scarcity

Resource scarcity is an increasing threat to future economic growth and a real challenge to the manufacturing industries, especially scarcity of fresh water, oil and gas, and some metals. Secure resource provision needs to be supported by healthy ecosystems, the vitality of which depends on biodiversity. The TEEB D3 report (UNEP 2010) for business has highlighted what is called the "impacts and dependencies" of the manufacturing industry on biodiversity and ecosystem services, reflecting the footprint of facilities and the pollution arising from production processes, as well as the role of suppliers of raw materials or semi-finished goods. These linkages are often complex and sector-specific. In the case of direct impact and dependency on biodiversity, the industries most implied include the pulp and paper industry as well as the textile and leather industry. If one considers high dependence on specific *ecosystem services*, this points to a wider range of industries. What they face is dependencies that pose risks associated with operations, markets, finance, regulations and reputation. A clear operational risk is that of increased scarcity and cost of natural resources.

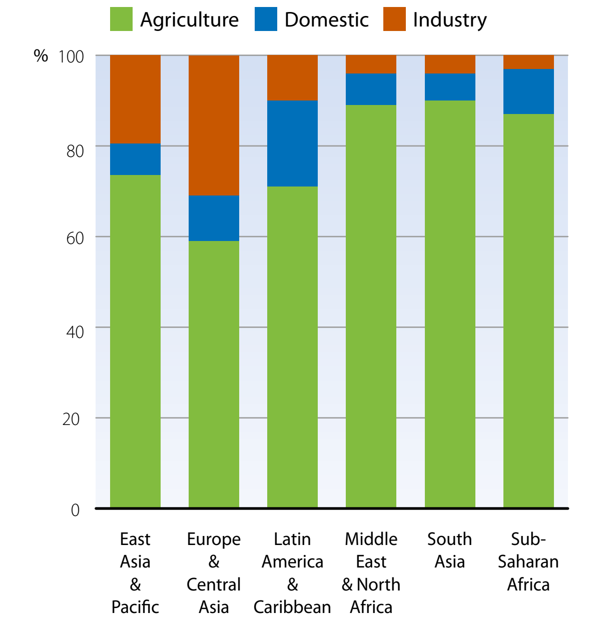

Figure 3: Water demand in end-use by region

Source: World Bank (2008)

Land use is mainly a problem related to agriculture and food production, rather than industrial production (UNEP, 2010a). The exception may be the future production of biomass for energy and feedstock purposes in industry. But industry is likely to face a significant challenge with regard to water in some countries or regions although it is responsible for less than 10 per cent of water use globally. Agriculture dominates with 70 per cent, followed by the energy sector and domestic uses with each 10 per cent (UNESCO 2009).

Owing to expected high growth of industrial production, *water use* by industry is expected to grow to over 20 per cent of global total demand by 2030 (Water Resources Group 2009). At the same time, by 2030, a potential water shortage of 40 per cent of expected demand compared to maximum sustainable supply is projected at the global level. The extent to which industry drives water demand is highly differentiated by region and river basin (see World Bank 2008 and Figure 3). The implications of this are that industries operating in regions of high water stress, and regions where industrial water demand is relatively important compared with other water demand, must improve their water productivity greatly or relocate to more water-abundant locations. This is particularly true for industries with high water use, such as the paper and pulp, textiles and leather, and the steel industries.

Demand for water by industry (and for the electric power sector) increasingly competes with water demand by agriculture and urban consumers. In addition, all of this needs to be balanced with water demand by ecosystems and biodiversity. Water treatment is a necessary precondition for industrial (or consumer) water use. About half of industrial water use is for cooling purposes, and about a fifth of this water is lost as vapour, but much of the other four-fifths can be used downstream for other purposes (although the discharge of heated water can be harmful to aquatic ecosystems). The best way to reduce water loss for cooling large central

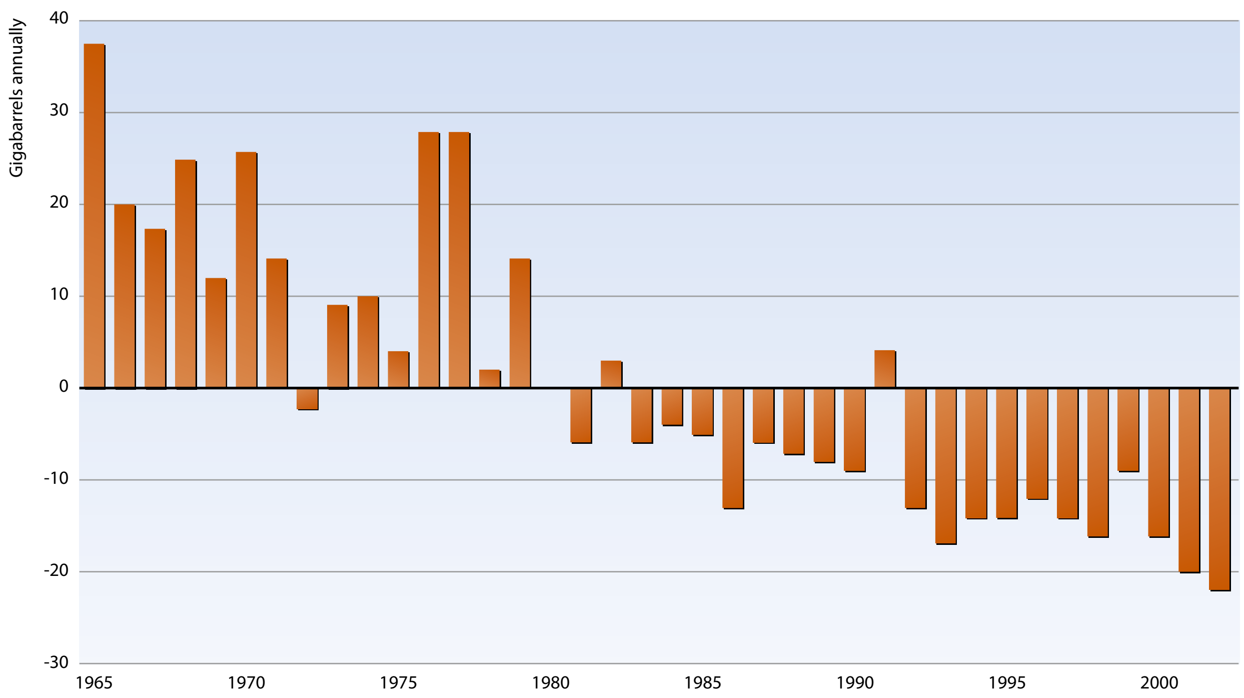

Figure 4: Discovery rate of oil trend, 1965 – 2002

Source: Heinberg (2004)

power facilities is to find productive uses for the heat. This strategy, called co-generation or combined heat and power (CHP), is applicable in urban areas, industrial parks and in buildings generally, but its widespread application requires a major change in the structure of the electric power grid. Other industrial water uses include quenching of hot coke or red hot steel ingots, wood pulping, washing, rinsing and dyeing of textiles, tanning of leather, and surface finishing of metals (including electroplating). These uses leave polluted and sometimes toxic waste streams that need treatment (which uses even more water), and whose costs in many instances are not reflected in the cost of production.

Reserves of easily recoverable oil are diminishing, stimulating technological innovation to extract oil from deep ocean underwater reservoirs and non-conventional sources, such as oil and tar sands, and natural gas from shale, as a close substitute for many uses of petroleum. Since the early 1980s, the amount of new oil discovered each year has been less than the amount extracted and used (Figure 4). The overall peak is only a question of time. However, market forces including high prices may reduce demand and increase the use of substitutes, causing demand to peak before supply. Some think peak oil may still be 20 years in the future. Others think it has happened already (see Campbell and Laherrère 1998, Campbell 2004, Heinberg 2004, Strahan 2007).

The energy and other costs of replacing oil exploration and development are rising. The energy return on investments in energy (EROIE) of oil discovered in the 1930s and 1940s was about 110, but for the oil produced in the 1970s it has been estimated at 23, while for new oil discovered in that decade it was only 8 (Cleveland et al. 1984). Decades ago, only 1 per cent of the energy in oil discovered was needed to drill, refine and distribute it, but since then the EROIE has declined drastically. In the case of deep-water oil, the EROIE is not above 10. For Canadian tar sands the EROIE appears to be only about 3, which means that a quarter of all the useful energy extracted is needed for the extraction itself. These costs are reflected in the rising price of oil (and gas, which is a partial substitute) and are a sign of increasing oil scarcity.

High quality *metal ores* are also gradually being depleted (OECD 2008). While absolute scarcity is not yet perceived as an immediate problem for most metals, the indicators on the life expectancy of reserves (cf Tables 1 and 2) show that lower grade ores must be used. However, in order to do so, more energy is needed to extract the useful metal content, adding marginally to GHG emissions. And whilst metals appear above ground in our economies in increasing quantities, a UNEP Resource Panel report on metals has shown the opportunity for much improved recycling rates (UNEP 2010b). Metals such as iron and steel, copper, aluminium, lead and tin enjoy recycling rates that vary between 25 and 75 per cent globally, with much lower rates in some developing economies. Improved recovery and recycling rates are also important for "high-tech" specialty metals that are needed in manufacturing to make key components for products that range from wind turbines and photovoltaic panels to the battery packs of hybrid cars, fuel cells and energy-

	WORLD Rate of change			OECD Rate of change			BRIICS* Rate of change			RoW** Rate of change		
	2002	1980–2002	2002–2020	2002	1980–2002	2002–2020	2002	1980–2002	2002–2020	2002	1980–2002	2002–2020
Amounts extracted (billion tonnes)												
Total	55.0	36%	48%	22.9	19%	19%	17.7	67%	74%	14.4	35%	63%
Metal ores	5.8	56%	92%	1.8	41%	70%	2.2	110%	100%	1.9	30%	104%
Fossil energy carriers[a]	10.6	30%	39%	4.1	12%	6%	3.7	58%	59%	2.9	31%	60%
Biomass[b]	15.6	28%	31%	4.5	11%	6%	5.9	49%	33%	5.2	25%	50%
Other minerals[c]	22.9	40%	54%	12.6	21%	21%	5.9	81%	115%	4.4	58%	63%
Per capita (tonne/capita)												
Total	8.8	-4%	22%	20.0	0%	8%	6.0	19%	51%	6.7	-16%	20%
Metal ores	0.9	11%	58%	1.5	19%	54%	0.7	51%	73%	0.9	-19%	51%
Fossil energy carriers[a]	1.7	-8%	14%	3.6	-6%	-4%	1.3	13%	38%	1.3	-18%	18%
Biomass[b]	2.5	-9%	8%	3.9	-6%	-4%	2.0	7%	15%	2.4	-22%	11%
Other minerals[c]	3.7	-1%	27%	11.0	2%	10%	2.0	30%	86%	2.0	-2%	21%
Per unit of GDP (tonne/1000 USD[d])												
Total	1.6	-26%	-14%	0.8	-33%	-24%	4.6	-35%	-32%	4.5	-21%	-26%
Metal ores	0.2	-15%	11%	0.1	-20%	9%	0.6	-18%	-23%	0.6	-24%	-8%
Fossil energy carriers[a]	0.3	-29%	-19%	0.1	-37%	-32%	1.0	-38%	-38%	0.9	-24%	-28%
Biomass[b]	0.4	-30%	-24%	0.2	-37%	-32%	1.5	-42%	-48%	1.6	-27%	-32%
Other minerals[c]	0.6	-24%	-11%	0.4	-32%	-22%	1.5	-29%	-17%	1.4	-8%	-26%

Notes: a. Crude oil, coal, natural gas, peat. b. Harvest from agriculture and forestry, marine catches, grazing. c. Industrial minerals, construction minerals. d. Constant 1995 USD. * BRIICS = Brazil, Russia, India, Indonesia, China and South Africa. ** RoW = Rest of the World

Table 1: Global resource extractions, by major groups of resources and regions
Source: OECD (2008)

Metal ores[a]	1999 reserves (tonnes)	1997–99 average annual primary production (tonnes)	Life expectancy in years[b], at three growth rates in primary production[b]			Average annual growth in production 1975–99 (%)
			0%	2%	5%	
Aluminium	25×10^{9}	123.7×10^{6}	202	81	48	2.9
Copper	340×10^{6}	12.1×10^{6}	28	22	18	3.4
Iron	74×10^{12}	559.5×10^{6}	132	65	41	0.5
Lead	64×10^{6}	$3,070.0 \times 10^{3}$	21	17	14	-0.5
Nickel	46×10^{6}	$1,133-3 \times 10^{3}$	41	30	22	1.6
Silver	280×10^{3}	16.1×10^{3}	17	15	13	3
Tin	8×10^{6}	207.7×10^{3}	37	28	21	-0.5
Zinc	190×10^{6}	$7,753.3 \times 10^{3}$	25	20	16	1.9

Notes: a. For metals other than aluminium, reserves are measured in terms of metal content. For aluminium, reserves are measured in terms of bauxite ore.
b. With current production and consumption patterns, technologies and known reserves.
c. Life expectancy figures were calculated before reserves and average production data were rounded. As a result, the life expectancies in years (columns 4, 5, 6) may deviate slightly from those derived from reserves and average production (columns 2 and 3).

Table 2: Life expectancies of selected world reserves of metal ores
Source: OECD (2008)

efficient lighting systems (UNEP 2010b). With respect to the availability of critical metals, the EU published in 2010 a list of 14 critical metals or groups of metals that are important to its economy, where supplies may be adversely affected by shortages or political tension (cf Graedel 2009).

Against this background, resource-intensive sectors face a multitude of challenges. First, rapidly industrialising economies are building their infrastructure rapidly and requiring large amounts of resources. Competition over access to resources is likely to grow. Second, high quality metal ores are gradually being depleted. This leads to the use of lower grade ores, which require much more energy to extract its useful metal component. Third, at local level resource extraction can have significant impacts on ecosystems and landscape. Mitigating these impacts through environmental policy or industry initiatives can also increase the cost of extraction. Fourth, there are risks of security of supply and price volatility.

Not all industrial production sectors are equally affected by these challenges, and not all materials are equally important in terms of economic or environmental impacts. This is illustrated by Figure 6 that combines information about physical material use in Europe with the life-cycle environmental impacts per kilogram of material (UNEP 2010a). Many minerals that dominate consumption by mass are of marginal importance for global warming, human toxicity, land use, or an integrated 'Environmentally Weighted Material Consumption' index (Van der Voet 2005). Indeed, environmental impacts are dominated by fossil fuels, their derivatives (such as plastics), and biotic materials (UNEP 2010a).

Resource scarcities – absolute or relative, actual or perceived – impact the prices of commodities and manufacturing inputs. Since the mid-2000s, commodity prices have shown an increasing volatility, which is mainly owing to a series of energy, financial, and food crises. Economic recession, in turn, reduces demand for oil and can be followed by an equally drastic price decline that is further exaggerated by speculation. Thus, price volatility can seriously inhibit long-term "green" investment.

Since the early 2000s, other commodity prices, especially non-ferrous metals, have also been sensitive to short-term factors such as the boom in China coupled with recession in the USA, depreciation of the US dollar (all commodities are priced in US dollars), and speculative activity (Figure 5). In 2008, commodity prices exceeded previous records from the 1970s. Higher prices induce investment in alternatives, but excessive volatility tends to have the opposite effect, because it prevents rational planning.

It is important to differentiate between short and long-term impacts and trends. When prices for natural resources rise because long-term trends in demand begin to exceed long-term trends in supply, or when governments internalise some of the environmental costs of natural resource extraction or use to business, the response of market participants can facilitate the adjustment process. Manufacturers are more likely to adopt innovative technologies that can improve resource efficiency. To the extent that this is not fully sufficient to absorb the increase in costs, the selling price of their products will increase, providing an incentive for consumers to search for less costly substitutes in the market place. Meanwhile, exploration and development of additional resources will occur, and markets will reach a new equilibrium at a higher price that stimulates innovation.

Figure 5: Commodity metals price index, June 1990-May 2010 (2005 = 100), includes copper, aluminium, iron ore, tin, nickel, zinc, lead, and uranium price indices

Source: Index Mundi (2010)

2.2 The external costs of industrial air pollution

Most manufacturing processes cause, to varying degrees, air, water and soil pollution – costs to society and the environment that need to be accounted, or "internalised", and reduced. In this section, the focus is on air pollution. Besides GHG emissions, industrial facilities release pollutants such as particulate matter, sulphur dioxide, nitrogen dioxide, lead, and chemicals that react to form ground-level ozone. These hazardous air pollutants can cause health and safety problems that are well known and degrade ecosystems. Some studies have sought to quantify the health and other costs of air pollution. For instance, the cost of air pollution in China, which was estimated in 2005 at 3.8 per cent of GDP, was found to be mainly driven by increasing industrialisation, which depends on coal-fired power plants and is led by an increasing urban population (World Bank 2008; cf Wan You and Qi 2005). Chinese coal on average contains 27 per cent ash and up to 5 per cent sulphur.

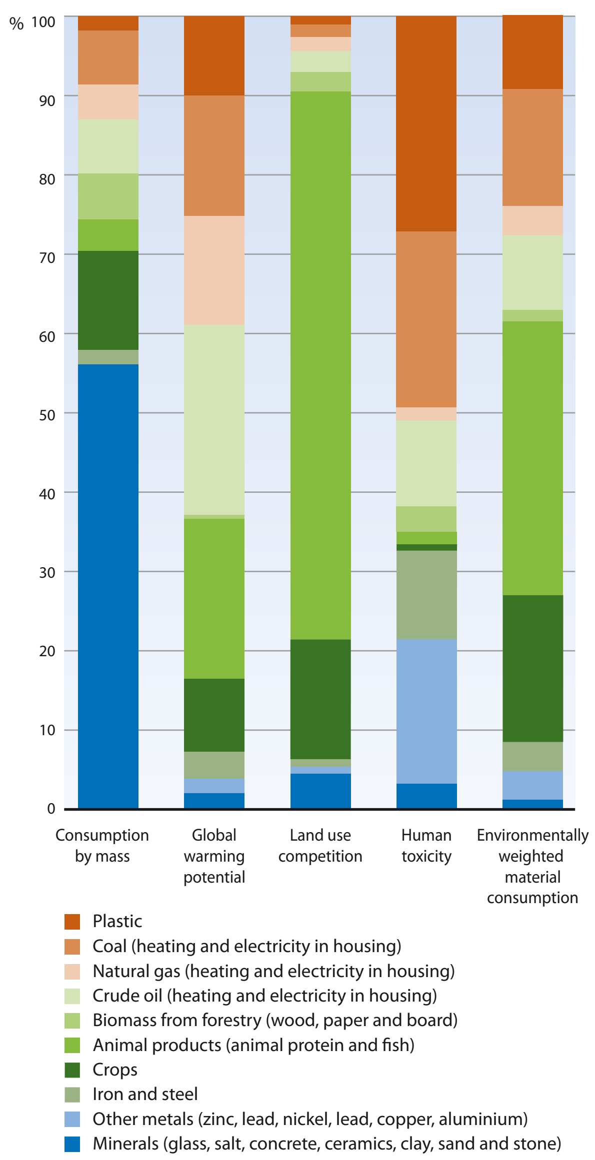

Figure 6: Relative contribution of material groups to environmental problems (EU27 + Turkey)

Source: UNEP (2010a)

Country	Year	GDP (per cent)
China	2008	1.16-3.8
European Union	2005	2
Ukraine	2006	4
Russia	2002	2-5
USA	2002	0.7-2.8

Table 3: Cost of air pollution from sulphur dioxide, nitrogen dioxide, and volatile organic compounds as a percentage of GDP

Source: Adapted from World Bank (2008), Markandya and Tamborra (2005), Strukova et al. (2006), Bobylev et al (2002), Mendelsohn and Muller (2007)

In the USA, damage from air pollution, mostly (95 per cent) in the form of health costs, is estimated to amount to between 0.7 per cent and 2.8 per cent of GDP. This estimate depends on assumptions about the value of life, as a function of age, and the relationship between exposure and mortality (Mendelsohn and Muller 2007). The USA data, taken from 10,000 locations, are consistent with European data. In Europe, the greatest contributors to emissions of particulate matter in 2000 were from the energy and electric power sectors (30 per cent), road-transport (22 per cent), manufacturing (17 per cent) and agriculture (12 per cent) (Krzyzanowski et al. 2005).

The cost estimates presented in Table 3 are based on human health effects, including premature mortality, chronic illness (such as bronchitis and asthma), and several acute illnesses. Muller and Mendelsohn (2007) also measure the damages from reduced crop and timber yields, impaired visibility, deterioration of man-made materials, and diminished recreation services, although the health-related damages constitute 95 per cent of the total (not counting GHGs). Another 2009 assessment, by the US National Research Council, found that burning fossil fuels costs the USA about US$120 billion a year in health costs, mostly because of thousands of premature deaths from air pollution.

The IEA and IIASA have estimated the cost of control policies for air pollution caused by the combustion of fossil fuels to be US$190 billion in 2005, some of it paid and some unpaid. This cost is projected to increase in a business-as-usual (BAU) scenario by a factor of three by 2030, owing to higher activity levels and increasingly stringent controls (IEA, IIASA 2009). However, the avoided costs to health and the environment are much greater, resulting in a highly favourable balance of benefits and costs. In addition, the costs of end-of-pipe pollution controls can be reduced by cleaner production approaches in management, cleaner raw material selection and cleaner technologies that reduce emissions and integrate by-products into a production value chain.

Air pollution and climate change are linked in several ways, and they could be beneficially addressed by integrated policy (Raes 2006). The analysis, using IIASA's GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model, reveals that significant co-benefits on local air quality can be expected from reduced GHG emissions and that climate change mitigation measures would cut SO_2, NO_x and particulate matter emissions at no extra cost and reduce local negative health impacts from fine particulate matter accordingly (IIASA 2009).

2.3 Hazardous substances and waste

Other significant environmental externalities at a global scale include impacts associated with hazardous substances and waste. The waste sector produces pressure on the environment through releases from

Location	Date	Cost (US$)	Number of fatalities and injured
Chemical industry			
Bhopal, India	03/12/1984	US$320 million in claims & compensation; US$10 million in economic, medical, social, environmental rehabilitation. However, the Indian government estimated the cost of the Bhopal disaster at US$3.3 billion.	2,800 fatalities and estimated 170,000 long-term adverse health effects
Toulouse, France	21/09/2001	€2 billion (environmental and social cost)	31 fatalities and 4,500 injured
Oil & Gas industry			
North Sea	06/07/1988	US$3.4 billion (mostly clean-up cost)	167 fatalities
Gulf of Mexico	20/04/2010	US$6.1 billion (as of 09/08/2010), (containment, relief, grants to the US Gulf states, claims paid, and federal costs); creation of a US$20 billion escrow account for clean-up and other obligations.	11 fatalities (oil platform workers)

Table 4: Examples of major industrial accidents and related economic and social costs

Source: Adapted from Mannan (2009), Grande Paroisse – AZF (2010), Kuriechan (2005), and BP (2010)

landfills, domestic and commercial waste-water treatment, and industrial wastewater. According to Havranek (2009), the waste management sector in the EU in 2005 generated external costs of €2.7 billion (assuming a low figure of €21 per ton of CO_2-eq emissions). A large component of this was owing to emissions of methane. For comparison, in the same year, the chemical industry in EU 27 produced €3.6 billion of external costs attributed to GHG emissions, which is a similar order of magnitude.

Releases of toxic substances cause health and safety problems and ecosystem degradation. Some countries have made significant progress by applying cleaner production, product substitution and end-of-pipe measures. In developed countries, toxic emissions have been one of the few success stories, with releases and exposure diminishing while production and GDP grew. This is related to the fact that most toxic substances are emitted as small mass flows, and for which substitution or emission reducing measures are relatively easy to achieve. Production patterns have changed radically, with industries based in developed countries focusing on high-value chemicals and pharmaceuticals. The manufacture of high production volume (HPV) chemicals on the other hand has been progressively migrating to developing countries, where regulatory frameworks are often lacking and where costs for the sound management of industrial (hazardous) waste are rarely internalised.

In the absence of good waste management, particularly the following industries may face toxicity challenges:

- Textile industry and leather industry in relation to dying and tanning products;
- Paper and pulp industry in relation to bleaching processes and related water emissions;
- Chemical and plastics industry, depending on the type of chemicals produced; and
- High-temperature processes such as in the cement and steel industry, where the formation of by-products or emissions of metals can be a problem.

Data provided by the International Council of Chemical Associations indicate that worldwide chemical sales in 2007 were €1.8 trillion, a 28 per cent increase from 2000 (see Perenius 2009). Over 60 per cent of these sales originated in OECD countries (1.1 trillion Euros). The BRIICS (Brazil, Russia, India, Indonesia, China, and South Africa) countries account for another 20 per cent of these sales (400 billion Euros in 2007). Of the hundreds of thousands of chemicals on the market, only a small fraction has been thoroughly evaluated to determine their effects on human health and the environment. Some chemicals that have been used in large quantities for many years are now suspected of carcinogenicity or teratogenicity. Some of the most toxic and dangerous chemical products (such as DDT) have been phased out, at least in the OECD countries. Adverse human health effects of chemicals include acute and chronic poisonings, neurodevelopmental disorders, reproductive/developmental disorders, and cancer (WHO 2004). Preventing chemical pollution at the source avoids generating harmful wastes and emissions while reducing and eliminating costs of cleanup.

Gaps in applying standards for industrial safety and accidents give historical examples of the risks and societal costs that can be associated with industrial production, in particular where hazardous substances are involved. ILO global figures for 2003 indicated that there were about 358,000 fatal and 337 million non-fatal occupational accidents in the world and 1.95 million died from work-related diseases. The number of deaths caused by hazardous chemicals alone was estimated at 651,000. When taking into account compensation, lost working time, interruption of production, training and retraining, medical expenses, social assistance etc., these losses are estimated annually at 5 per cent of the global gross national product. Latest ILO estimates indicate that the global number of work-related fatal and non-fatal accidents and diseases does not seem to have changed significantly in the past ten years. One complication in manufacturing and ship-building is the distribution of occupational safety and health (OSH) obligations in the principal contractor–subcontractor relationship (ILO 2009).

The cost of industrial accidents represents a great source of public and private expenditure and social distress. Over the past three decades, a rough cost assessment of only a few of the major industrial accidents worldwide shows that a minimum of US$40 billion have been spent on addressing the damages. If smaller incidents are taken into account, the real economic cost is likely to double, while deaths and injuries would be in the scale of several hundreds of thousands. Some major incidents are listed in Table 4. Clearly, there are global benefits in human and environmental health associated with cleaner and safer industrial production, which has to be part of a transition to green manufacturing.

3 Opportunities – Strategic options for the manufacturing sector

In its *Vision 2050* report, the WBCSD (2010) describes a world in which the manufacturing industries follow life-cycle approaches that enable dematerialisation and expanded service systems. In a sustainable world of about 9 billion people by 2050, a complete range of new products and services is offered, based on high longevity, low embodied water, as well as low-energy and material content. This transition will not happen overnight, and it will require substantial investment. A major challenge is one of transition in industrial production, to become less carbon and material intensive while at the same time preserving jobs or reinvesting in completely new employment opportunities. This is particularly relevant for developing and emerging economies that currently invest heavily in conventional production infrastructure. Both at the country and industry sector level, improved resource-efficiency and decoupling offers the opportunity of competitive advantage and a sustainable future.

To what extent will "green" investments in efficiency have a more favorable payoff than conventional investments? Big companies normally set their "hurdle" rate of return on investment (ROI) at around 25 per cent, pre-tax. There is overwhelming evidence of significant opportunities for efficiency investments that yield much higher rates of return, even under current economic conditions. The economic opportunities increase dramatically at higher carbon prices.

3.1 Decoupling and competitive advantage

As indicated earlier, historical evidence shows that declining energy intensity in industry and relative decoupling have typically been offset by increases in energy demand associated with higher levels of GDP. In addition, there may have been additional demand for energy as an input owing to a decline in its relative price and to the increase in economic growth owing to the gain in resource efficiency itself (the two effects together are sometimes called the "rebound effect"). Overall emissions, energy use and material use have kept on growing despite lower emission, energy and material use per unit output as seen in Figure 7 (see Krausmann et al. 2009). Resource extraction *per capita* has been stable or increasing only slightly. What economies world-wide need is *absolute* decoupling of the environmental pressure associated with resource consumption from economic growth. This will be easier to achieve to the extent that resource use itself becomes more efficient.

In recent decades, OECD countries have decreased their extraction intensity per US dollar of GDP, reflecting some decoupling of primary resource extraction from economic growth. This trend is expected to continue. The main drivers are increased applications of more material-efficient technologies (technology effect), shifts from the primary and secondary sectors towards the service sector (structural effect), and associated increases in material-intensive imports (trade effect) owing to outsourcing of material-intensive production stages to other world regions (OECD 2008). For the world as a whole, of course, there is no trade effect because one country's imports are another country's exports.

The decoupling of material use from GDP growth has been less pronounced in fast-growing transition

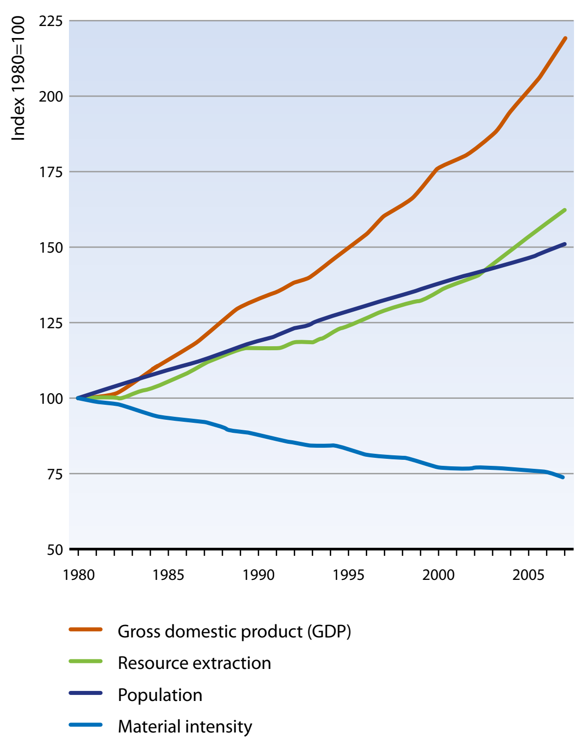

Figure 7: Global relative decoupling trends 1980-2007

Note: This figure illustrates global trends in resource extraction, GDP, population and material intensity in indexed form (1980 equals a value of 100).

Source: SERI (2010)

economies that need to build infrastructure, which requires more resources (in mass terms) than in economies with low growth rates (cf Bleischwitz 2010). Similarly, the energy-intensive industrial sectors are not equally affected. The cement industry drives large material flows, but of relatively non-scarce resources such as limestone and clay. Iron ore and bauxite are not particularly scarce, and near substitutes are available. The paper and pulp and the natural fibre-based textile industry use renewable resources where the challenge is to avoid using them beyond the maximum sustainable yield. The challenges for the electrical and electronic industry may be more fundamental. High grade (>1per cent) and easy-to-refine copper ores are becoming scarcer and low-grade ores need more energy in the extraction and refining stages. Rarer metals such as silver, indium and tellurium are mostly extracted from other metallurgical wastes.

One of the major effects of the globalised nature of the world economy is the increasing shift of the manufacturing base from developed to developing and transition economies. This means that associated environmental damages from local pollution are also shifting. Accordingly, decoupling energy use and CO_2 emissions from GDP growth needs to be considered in the international context, rather than in terms of individual countries (see OECD 2008a). The relationship between Global Competitiveness Index ratings, material productivity and the introduction of leading technology strategies have been highlighted in recent research by Bleischwitz et al. (2009, 2010). A correlation was performed between resource productivity (Domestic Material Consumption) and competitiveness data by the World Economic Forum. Covering 26 countries, it showed a positive relationship between the material productivity of economies (measured by GDP in purchasing power parity US$ per kg DMC) and their competitiveness index scores.

Improving the environmental efficiency of production at the global level can occur through technology and knowledge transfer from developed economies or through technology spillovers that occur as a result of international investment and globalised supply chains. With demand increasingly being driven from outside the advanced economies, these transfers and spillovers have dual benefits – not just reducing the extent of environmental damage exported from developed countries, but also helping developing economies shift to a more resource-efficient growth path (Everett, Ishwaran, Ansaloni, Rubin 2010).

3.2 Innovation in supply and demand

Making society more efficient with regard to the use of energy, water, land and other resources is a challenge that requires changes along the full chain of production and consumption. Authors such as Von Weizsäcker et al. (1997, 2009) have suggested that one way to realise "Factor X"[2] improvements in resource productivity would be a radical change in end-use products, new ways of (e.g. shared) using products (e.g. sharing), and changes in consumption habits. This includes consideration of concepts such as "sufficiency" and asking critical questions about the function and service of proposed products.

It also requires a life cycle approach, which is what the WBCSD (DeSimone and Popoff 1997) has pursued in promoting the concept of eco-efficiency over the last decade. This concept focuses on those resource efficiency measures that also generate a positive rate of return to business on the required investments. Eco-efficiency provides a graphic tool for combining different measures, yet still has shortcomings in allowing quantification and comparison based on empirical indicators. The guidelines behind eco-efficiency include reducing the material and energy intensity of products, enhancing material recyclability, extending product durability and increasing the service intensity of products. Eco-efficiency in manufacturing can be measured through indicators related to (i) resource-use intensity and (ii) environmental-impact intensity. Considering its application at national level, UNESCAP (2009) has defined the following as key indicators for manufacturing in the Asia Pacific Region:

Resource-use intensity:	**Environmental impact intensity:**
Energy intensity [J/GDP]	CO_2 intensity [t/GDP]
Water intensity [m3/GDP]	BOD intensity [t/GDP]
Material intensity [DMI/GDP]	Solid waste intensity [t/GDP]

Considering the full life-cycle and chain of supply and demand, Tukker and Tischner (2006) proposed a range of step-change measures along a full production-consumption chain, and speculated about their factor efficiency potential (see Table 5). Importantly, this reflects a full value-chain perspective, one that reflects product and service combinations as well as producer and user or consumer challenges. The entry point in this chapter is the upstream side and base industries such as steel and iron, cement, chemicals, paper and pulp, and aluminium – industries that supply primary materials for the manufacturing of products such as cars, buildings and refrigerators that end-users know from daily life. Considering the full value chain can identify a range of

2. "Factor X" relates to a factor 4 or 10 improvement in energy and resource efficiency. Achieving factor X would in some cases require the application of disruptive new technologies. In addition, the concept of "exergy" promoted by Robert Ayres and others focuses specifically on "useful energy" (as opposed to static energy and mass) and efficiency as a ratio of useful output compared to resource input.

Production side *Eco-efficiency strategies*				Consumption side *Sufficiency strategies*
Mining and production	Production of end use products and services	Use of products and services	Expenditure mix	Quality of life realised
New technology and end of pipe	Red-design of end-use products	Intensifying use ("Product service system")	Shifting expenditure to low impact products	Lowering expenditure, improving quality of life/Euro spent
20–50% factor x	20–50% factor x	Factor 2	Factor 2	Factor 2–4

Table 5: Strategies for factor-efficiency improvements and decoupling through stages in the full production-consumption chain

Source: Tukker and Tischner (2006)

areas for innovation and green investment, including product design and development (PD), material and energy substitution (MES), process modification and control (PM) and new, cleaner technologies and processes (CT). These become the building blocks in either a supply or demand-side strategy for improving resource efficiency in manufacturing.

A *supply-side strategy* involves redesign and improving the efficiency of processes and technologies employed in the major materials-intensive subsectors of the manufacturing sector (ferrous metals, aluminium, cement, plastics, etc.). On the other hand, if a green economy means improving not only productivity but also efficiency by a factor of four or more, a demand-side strategy is also required.

A *demand-side strategy* involves changing the composition of demand, both from within industry and from final consumption. This requires modifying output, i.e. to use final goods embodying materials and energy much more efficiently and/or to design products that require less material in their manufacturing. For instance, the need for primary iron and steel from energy-intensive integrated steel plants can be reduced by using less steel downstream in the economy (i.e. in construction, automobile manufacturing, and so on).

The supply-side and demand-side approaches consist mainly of the following components:

■ *Re-design products* and/or *business models* so that the same functionality can be delivered with fundamentally less use of materials and energy. This also requires extending the effective life-time of complex products and improving quality, by incorporating repair and remanufacturing into a closed-cycle system.

■ *Substitute* "green" inputs for "brown" inputs wherever possible. For example, introduce biomass as a source of chemical feedstocks. Emphasise process integration and upgrade of process auxiliaries such as lighting, boilers, electric motors, compressors and pumps. Practice good housekeeping and employ professional management.

■ *Recycle* internal process wastes, including waste-water, high temperature heat, back pressure, etc. Introduce combined heat and power (CHP) if there is a local market for surplus electric power. Use materials and energy with less environmental impact, e.g. renewables or waste as inputs for production processes. Find or create markets for other process wastes, especially organics.

■ Introduce new, *cleaner technologies* and improve the efficiency of existing processes to leapfrog and establish new modes of production that have a fundamentally higher material- and energy efficiency. To start with, major savings potential in manufacturing lies in improving the resource efficiency of existing processes.

■ *Redesign systems*, especially the transportation system and urban infrastructure down-stream, to utilise less resource-intensive inputs. The first target must be to reduce the need for and use of automotive vehicles requiring liquid fuels in comparison to rail-based mass transportation, bus rapid transit and bicycles.

Note that these transitional changes will occur automatically *only* to the extent that they are perceived by business managers and owners to increase competitiveness. Moreover, the manufacturing sectors are intermediates, which means that what they produce depends both on the availability and cost of raw materials and on the demand from downstream sectors, final consumers, and governments. The latter can influence business decision-making by introducing new standards or subsidies. To ensure that a strategic transition to sustainable industrial production is realised in different parts of the world, both public and private investment in "leap-frogging" technologies would be highly desirable.

Despite technological advances, there will always be some inefficiency and waste. What is possible, however, is to use resources much more efficiently than they are used now. There is plenty of room for doing so. The USA's economy today converts primary energy into useful work – mechanical, chemical or electrical – with an aggregate efficiency of 13 per cent (Ayres and Warr 2009, Ayres and Ayres 2010). IEA data suggest that

Russia, China and India remain less energy efficient than the USA (at least in the industrial sectors) (IEA 2009b). Japan, the UK and Austria are more efficient, overall, than the USA (20 per cent) (Warr et al. 2010). But this still means that *more than 80 per cent, or four-fifths, of the high quality energy extracted from the earth is wasted*. To cut that waste by only a quarter or a third could produce significant economic gains. From a macro-economic perspective, this is an enormous opportunity.

Closed-loop, circular systems in manufacturing

Drawing on the principles of industrial ecology, *closed-cycle manufacturing* is a particularly ambitious approach to supply-side innovation. This concept refers to an ideal manufacturing system that maximises the useful life of products and minimises the waste and loss of valuable and scarce metals. At a broader systems level, another version of closed-cycle manufacturing is industrial symbiosis or eco-industrial parks. They are modelled on the Kalundborg (Denmark) example, within which wastes from certain manufacturing operations can be used as raw materials for others. In Kalundborg, an oil refinery that produces low temperature waste heat (warm water) is used for greenhouses suppling organic raw materials for a drug company that manufactures insulin. There is a coal-burning power plant from which desulfurisation wastes are used by a wallboard manufacturer (Ehrenfeld and Gertler 1997). Although there have been a number of attempts to create eco-parks – there are now over a hundred around the world – it has been hard to reproduce such synergies elsewhere. One reason is the need for an eco-park to grow around a fairly large (and long-lived) basic industry that generates predictable wastes, with usable elements or components that smaller operations next door can utilise.

At the product level, closed-cycle manufacturing achieves life-cycle efficiency by facilitating maintenance and repair, reconditioning and remanufacturing, with recycling at the end, in contrast to today's linear "throw-away" paradigm. The usual one-way flow of products from the factory to the salesroom is changed to a two-way flow. If the useful life of all manufactured products (and buildings) were to be extended by 10 per cent, the volume of virgin materials (except fuels) extracted from the environment would be cut by a similar amount, other things being equal, and resource prices would tend to fall. This would eliminate jobs for miners, but it would employ more people in downstream stages – especially repair and renovation and recycling – and cut costs through the supply chain all the way to final consumers, who would then have more disposable income. It is important to recognise that radical change is seldom painless. Schumpeter's phrase "creative destruction" expresses this idea very well. Extending product life may also cut the rate of technological improvement. The lifetime extension of a product through increased reuse and recycling often results in relatively higher energy consumption levels because recent technological improvements have not been embodied in the reused products (such as cars and refrigerators). Life-cycle assessment of many products shows that most of the environmental pressure arises from their use and disposal rather than from the direct and indirect impacts of their production. The inability to capture technological improvements is especially acute in the area of electric power generation, where tough "new source standards" have inhibited the replacement of old generating facilities.

Remanufacturing is also becoming increasingly significant, particularly in areas such as motor-vehicle components, aircraft parts, compressors, electrical and data communications equipment, office furniture, vending machines, photocopiers, and laser toner cartridges. The Fraunhofer Institute (see UNEP, ILO et al. 2008) in Germany has calculated that remanufacturing operations worldwide save about 10.7 million barrels of oil each year, or an amount of electricity equal to that generated by five nuclear power plants. They also save significant volumes of raw materials. In the USA, it has been estimated that re-manufacturing is a US$47 billion business that employs over 480,000 people (UNEP, ILO et al. 2008). In terms of employment and economic impact, the remanufacturing industry rivals such giants as household consumer durable goods, steel mill products, computers and peripherals, and pharmaceuticals.[3]

Some companies are now introducing specialised collection, sorting and dismantling plants around the world, either to save spare parts or to produce low-cost versions of their top-of-the line products. This encourages product redesign to facilitate the process. Caterpillar is probably the world's largest re-manufacturer, with a global turnover of US$1 billion and plants in three countries. About 70 per cent of a typical machine (by weight) can be re-used as such, while another 16 per cent is recycled (Black 2008). Large diesel engines are routinely re-manufactured. Aircraft are essentially remanufactured continuously by replacement and reconditioning of most parts other than the body and frame, which is why some DC-4 and DC-6 aircraft manufactured in the 1930s or 1940s were still in use 50 years later. Xerox and Canon, which began remanufacturing photocopiers in 1992, are among the companies that have pushed this concept.

3. For an analysis of over 7000 remanufacturing firms in the USA, see the database and research by Lund (1996) and Hauser and Lund (2003) at Boston University (www.bu.edu/reman/).

The major obstacle to re-manufacturing is that strategies for extending the useful life of manufactured products depend upon active cooperation from original equipment manufac turers (OEMs). The OEMs have resisted this approach to date. In fact, the current trend is exactly the opposite: products are increasingly being made as un-repairable as possible, so that old products are discarded and usually sent directly to landfills. Another barrier is the fact that most products are not sold directly by their manufacturers or agents. This makes collection and return difficult. OEMs would have difficulty providing warranties for products remanufactured by other firms. Also, some companies are reluctant to market re-manufactured products in competition with their own new machines. Instead, customers are encouraged to replace old, but still functioning products with new ones. This problem is less acute in product categories (such as computers) with rapidly changing technologies, where new products have much greater functionality than reconditioned or re-manufactured old ones. Most consumer product companies see repaired, renovated or remanufactured products as directly competing with their new products and will continue to do so unless legislation is enacted or pricing differentials are introduced.

Three central components in the *waste minimisation* hierarchy are the "3Rs": reduce, re-use and recycle (see the Waste chapter). Following repair and remanufacturing to enable the re-use of products, *recycling* is a key step in the closed manufacturing system. This can support the use of the by-products of production processes, whilst also providing solutions in the substitution of inputs in manufacturing. The most important input substitution in the metals industry *per se* is the use of scrap in place of ore. In the USA and Europe half or more of the carbon steel production is now based on scrap. Scrap is routinely sorted into grades, depending on the presence of contaminants. Research on ways to separate contaminant metals from the iron is needed, if only to facilitate recovery of the chromium, zinc, copper and so on. Yet, surprisingly, the recycling rate for iron and steel has dropped in recent years from a high of 60 per cent in 1980 to 35 per cent in 2006. The IEA projections assume that the decline will reverse and that a recycling rate of around 55 per cent will be achieved by 2050 (IEA 2009b). However, a significantly higher rate may be achievable by appropriate policy interventions.

Recycling is especially energy-efficient in the cases of aluminium and copper. Recycled aluminium requires only five per cent as much energy as primary production, but the recycled product, which often contains alloying elements, is not easy to roll into sheets or foil. Effective ways to purify the recycled metal (and to recover the alloying elements) would be very valuable. In the case of copper, a single ton of metal requires the mining and processing of anywhere from 100 to 300 tons of ore (depending on the country), so the recycled copper requires much less energy than the "virgin" metal from ore (Ayres et al. 2003).

One of the most important (and under-exploited) near-term opportunities for improving energy efficiency in industrial processes lies in recycling high-temperature waste heat from processes such as coke ovens, blast furnaces, electric furnaces and cement kilns, especially for electric power generation using combined heat and power (decentralised CHP). Virtually all of these examples are technically suitable for small combined heat and power plants with paybacks of the order of four years, providing only that the power can be utilised locally.[4] The pulp and paper industry has reported heavy investment in CHP technology to *reduce energy consumption*, noting that (CHP) installations allow savings of between 30–35 per cent of primary energy (UNEP 2006). Where CHP is not an option, the next example of input substitution is the use of waste fuel, such as biomass or municipal waste.

On the demand side, numerous measures can reduce absolute water use through efficiency and recycling measures. Recycling waste water from a variety of industrial processes is increasingly important because of the scarcity of fresh water in conjunction with growing demand for water in many parts of the developing world, such as northern China and India. The world market for water treatment in 2008 was US$374 billion, of which US$70 billion was in the USA alone. Half of this market could be served by new modular systems using magnetic separation technology, which has been successfully applied to mining and industrial wastes as well as municipal wastewater (Kolm and Kelland 1975; Svoboda 2004).

Water used in chemical wood pulping is mostly recycled internally to recycle the chemicals. Metallurgical, chemical, textile and other surface-finishing operations generate polluted wastewater that must be treated before it can be re-used. In the longer term, there are numerous possibilities for reducing the need for water treatment after use by making the processes themselves more efficient or cleaner. In particular, the need for industrial cooling water can and should be reduced dramatically by introducing co-generation of electricity to take advantage of high-temperature heat that is currently wasted.

4. Under current rules in most countries, only the electric power companies can sell electricity. This means that the utilities are also monopolist buyers. The price at which they are willing to buy electricity from other producers is often too low to make the investment worthwhile.

4 Investment and resource efficiency

Making the investment decision to pursue green manufacturing opportunities requires careful consideration of real net benefits and longer term consequences of decisions made today. This includes consideration of research, development and design options that enable users and consumers to move away from the throwaway consumption paradigm. Some technology innovations hold potential for drastic gains in resource efficiency, while others – such as carbon capture and storage (CCS) – may bring more costs than benefits. The cases of energy and water resources display the importance of having appropriate regulations and pricing in place. The area of human resources and employment highlights the importance of carefully considering direct and indirect impacts, as well as the role of taxes, price elasticity and rebound effects.

4.1 Invvesting in material and energy efficiency

To create a greener economy, many believe that fundamental changes are needed – changes which some have referred to as a social-technological transition (e.g. Geels 2002). The magnitude of the challenges is underscored by the fact that current unsustainable systems ("socio-technical regimes") are locked-in by a multitude of demand- and supply-side-related factors. Yet, if the concept of closed-cycle manufacturing could be extended to mass-market products such as cars, washing machines, refrigerators and air-conditioners, the potential benefits to society would be significant. In the first place, by extending the average life-span of manufactured goods, the need for extracting virgin materials is correspondingly reduced. In the second place, repair, reconditioning, and "remanufacturing" are fairly labour-intensive activities, requiring relatively little capital investment. Thus, governments of developing countries have an interest in promoting imports of used goods which are capable of being remanufactured, not only in reducing global GHG emissions and resource consumption, but also in maintaining domestic employment and availability of modestly-priced goods for domestic consumption.

Most cleaner technology innovations will struggle to attract venture capital under current conditions, even in industrialised countries. Venture capital firms are looking for investment opportunities that offer high margins and require low capital expenditures and low-cost testing of their market potential. Changing this situation to encourage innovation, especially in transitional and developing countries, depends on the enabling conditions (section 5). Those innovations that have attracted venture capital interest in recent years are mostly related to the Internet or renewable energy. While investment in core clean energy (including energy efficiency) decreased in 2009 owing to the global economic downturn, there was a record investment in wind power (UNEP SEFI 2010).

The field of electronics recycling is another promising area for research and development. Currently, there is some recycling of television sets to recover lead and glass, but e-recyclers mostly try to recover silver and gold, without recovering other scarce metals. New processes exist for recovering liquid crystal, indium metal and glass (LCD) from discarded flat-panel TV screens (Black 2008). These LCD panels constitute an increasing share of electronic waste, and the recovery process may be profitable enough to justify significant investment in a more structured approach to the electronic waste recovery problem as a whole.

Design initiatives in these areas are clearly within the scope and in the interests of manufacturers, because they contribute to competitiveness and cut costs. However, there is another type of design innovation that is more directly relevant to overall resource efficiency, while being less profitable to manufacturers *per se*. This involves design changes to permit easier reconditioning, remanufacturing and (finally) recycling of scarce metals. For example, it is important to facilitate the separation of electrical and electronic components from structural components of appliances and vehicles. This is important both to recycle rare metals (silver, gold, platinum, indium, etc.) that are increasingly being used in electronic products, and to reduce the extent to which these same metals (especially copper) become unwanted contaminants of secondary (recycled) aluminium and steel. Clearly, there is a huge opening for design-for-reparability, remanufacturability and recyclability, i.e. for closed-loop manufacturing. In the case of used cars, open international markets currently provide incentives for material leakages that could be turned into business opportunities by using closed-loop systems.

A 2010 report from the Greco Initiative Regional Activity Centre for Cleaner Production (Greco Initiative) described the effects of applying many of the strategies discussed here to a variety of manufacturing industries in the Mediterranean region. The study found that with the use of alternative machines and production input, returns on investment (ROI) can be substantial. In the automotive industry ROI reached 250 per cent, in textiles

Countries	Sector	Energy-efficiency initiatives	ROI	Payback	CO_2 savings
Bangladesh	Steel	Reparation of leaks and insulation of pipelines	260%	3.5 months	137 tons/year
China	Chemicals	Installation of a heat recovery system to recover heat for a CHP	96%	7 months	51,137 tons/ year
Ghana	Textiles	Installation of hi-tech de-scaling equipment for the boiler and steam pipes. Water conservation measures resulted in comparable savings.	159%	4 months	Not available
Mongolia	Cement	Improvements in the dust control system (filter bags) using new electric motors.	552%	2 months	11,007 tons /year
Honduras	Sugar	Replacement of steam turbines in the crushing mill with electric motors, powered by CHP; surplus electricity sold to the grid	Not available	1 year	Not available

1. See the following link accessed June 2010: http://www.energyefficiencyasia.org/ 2. See the following link accessed June 2010: http://www.ghanaef.org/publications/documents/2savingenergyindustry.pdf
3. See the following link accessed June 2010: http://www04.abb.com/global/seitp/seitp202.nsf/0/316e45d4d67ae21bc125751a00321e72/$file/Sugar+mill+case+study.pdf

Table 6: Examples of investment and environmental returns from energy-efficiency initiatives in developing countries

Source: Adapted from Energy Efficiency Asia UNEP SIDA GERIAP[1], Energy Foundation Ghana[2,] ABB Switzerland[3]

26 per cent, in chemicals 9 per cent, and in electronics 6 per cent, with payback periods varying between 3.4 and 11.3 months. However, the magnitudes of identified savings were not large. On the energy-efficiency front, case studies from around the world show similar levels of economic and environmental benefits from energy-efficiency initiatives (Table 6).

The IEA (2008, 2009b) scenarios – aimed at realising emission levels by 2050 that limits GHG concentrations to 450 ppm and average temperature rise to 2-3°C – imply high expectations of both technological innovation and regulation. It presents a business-as-usual (BAU) scenario that includes regular resource- and energy-efficiency improvements, implementation of best-practice technologies, and profitable recycling and valorisation options that firms can implement profitably under existing market conditions[5]. The energy efficiency or carbon-reducing measures presented in the "Blue" scenario would be more difficult to implement, and less likely to yield positive returns on investment[6]. For example, the scenario assumes the use of expensive forms of carbon-neutral electricity, including power plants equipped with CCS to achieve almost two-thirds of the required reductions of CO_2. The IEA is frank in spelling out the cost implications, explaining that the drastic reductions in the Blue scenario would require the widespread use of regulatory policy instruments, such as economic instruments, that would gradually increase the price of carbon to US$150 per ton of CO_2 by 2050.

The case of CCS shows the advantage of an integrated resource-efficiency perspective, as opposed to pursuing investment decision-making focused on single measures (such as carbon emissions) at the cost of lower resource-efficiency and lower economic growth. CCS systems involve capturing, liquefying and injecting CO_2 deep into the earth's crust. CCS requires flue gases to be filtered and passed through a chemical process that dissolves the carbon dioxide in another chemical, then compresses and liquefies the carbon dioxide so that it can be pumped or shipped to a long-term storage site. The problem is that CCS requires a lot of energy. CSS systems being considered for cement plants today could double a current market price of US$70 per ton. In the case of electric power, a 500 megawatt power plant would need to use between 25 per cent and 40 per cent of its output to capture and store the CO_2 (Metz et al. 2005). This would increase the number of power plants needed to supply the same amount of electric power to the rest of the economy by a factor of 4/3 to 5/3, adding significantly to the cost of electric power.

4.2 Investing in water efficiency

Water scarcity and hence the costs and benefits of reducing water scarcity are highly region-specific. Overall, by 2030 there is expected to be a "water gap" between potential demand and reliable supply (4,200 bio m^3) of 40 per cent of potential demand (6,900 bio m^3). Industry is currently responsible for an estimated 10 per cent of global water demand, the energy sector for an equivalent amount and agriculture for 70 per cent. The fraction used by industry will probably rise beyond 20 per cent in the next decades, in line with the growth of industrial production (Water Resources Group 2009, OECD 2007, World Bank 2008, UNESCO 2009).

In some countries with high water stress, such as Jordan, Egypt, Tunisia, and Turkey, it has been estimated that unsustainable use of groundwater now already

5. This includes resource-efficiency measures such as enhanced steel, paper and aluminium recycling, and the use of secondary fuels and solid waste as secondary raw materials in cement kilns.

6. Unfortunately, IEA (2009a) does not provide information which energy efficiency measures presented in the 'Blue' scenario can be implemented with positive returns for industry.

reduces GDP by 1-2 per cent (World Bank 2007). For these countries alone this would imply a GDP loss of around US$10 billion. This report refrains from making extrapolations on a global scale owing to the strong regional character of the water gap problem. But since the physical water gap has to be closed, the question is how this can be done most cost-effectively.

The Water Resources Group (2009) has done probably the most comprehensive study globally into cost curves for measures that could close the water gap in four regions (China, India, South Africa, and the Sao Paolo area in Brazil). Total costs of all measures (including in other sectors as industry) to close the water gap are US$5.9 billion in India, US$21.7 billion in China, US$0.3 billion in Sao Paulo, and negative in South Africa. These numbers typically represent 0.5 per cent or less of GDP.

The measures to be taken in the industries examined in this chapter show a mixed picture. In India, measures to close the water gap have to be taken predominantly in agriculture and to a lesser extent in industry. Most water conservation measures technically possible in industry would yield a positive social benefit-cost ratio. However, their commercial profitability at the enterprise level depends upon water-pricing policies. In China, the paper and pulp, steel and textile industries are well positioned to enhance water efficiency at a profit for themselves, whereas the picture is unclear in South Africa. The findings for the textile industry in China are in conformity with anecdotic case studies in Turkey, where industrial users also pay for water supply and treatment, revealing a payback period of 3-5 years (Kocabas et al. 2009). However, in South Africa such investment would not seem to be profitable for industry because users do not pay a sufficiently high percentage of the costs of water supply and treatment.

Steel production facilities are often situated close to the ocean for shipping purposes and can use seawater for cooling purposes. A subsidiary of Arcelor in Brazil uses seawater for 96 per cent of total water used for its steel manufacturing. In South Africa, the proximity of a RAMSAR wetland has caused Saldanha Steel to build a zero-effluent plant and showing that it is possible for the steel industry to achieve zero water pollution levels (Von Weizsaecker 2009).

Improved monitoring of water use through emerging water accounting methods is an area where manufacturing companies can learn from agrifood industries. The Waterfootprint Network has highlighted, however, that the diversity of industrial products, the complexity of manufacturing production chains and differences between countries and companies makes it more realistic to determine average amount of water used for industrial products per unit of value (e.g. 80 litres per US dollar) rather than per unit or by the weight of the product.[7] Faced with unpredictable climate conditions, manufacturing industries are staring to investigate this more closely. In a benchmark survey of reporting on water use by a hundred multinational corporations, CERES (2010) found that 10 of the 15 chemical companies examined disclosed market opportunities related to products intended to save water or improve water quality. Four companies disclosed new investments in R&D to bring more water efficient products to the market. For example, Dow Chemicals reported on the construction of a new Water Technology Development Center to support its goal of driving a 35 per cent reduction in the cost of water reuse and desalination technologies by 2015.

4.3 Investing in a transition to green jobs

The industries analysed in this chapter employ more than 70 million workers[8]. During recent years these sectors have exhibited differing employment trends. Iron and steel, chemicals, pulp and paper and cement sectors have observed stagnating or declining levels of employment. Conversely, electrical and electronic products and textiles have experienced an expansion in their employment levels.

The manufacturing industries face serious deficits in decent work. From shortcomings related to occupational health and safety to rising informality, various dimensions of decent work are compromised. For example, operations in the iron and steel industry may expose workers to a wide range of hazards or conditions that could cause incidents, injury, death, ill health or diseases. The ship-breaking industry in Asia, a major supplier of recycled steel, is illustrative of poor health and safety conditions. In the textile sector, the need for greater flexibility is the root cause of relocations, a greater reliance on sub-contracting arrangements and consequent instability of employment.

Greening the manufacturing sector entails changes in the level and composition of jobs. In the metals value chain, for instance, significant green job creation opportunities are expected from the use and recycling of valuable byproducts and scraps. On the other hand, efficiency improvements in manufacturing tend to reduce the need for workers in the same industry unless there is a resulting increase in demand (rebound). While

7. The Waterfootprint Network has calculated industrial water uses that range from nearly 100 litres per US$ in the USA to 20-25 litres per US$ in China and India (www.waterfootprint.org/).

8. According to information from the ILO, the textiles industry employs 30 million workers; electric and electronic products 18 million; chemical industries 14 million, iron and steel 5 million, pulp and paper 4.3 million, aluminium 1 million, cement 850,000 jobs. All figures are approximations.

the impact of greener practices on employment should not be overestimated, the empirical evidence supports positive effects of green practices on jobs. Direct effects of greening options may be neutral or small, the indirect effects could be much larger (cf Lutz and Giljum 2009). This indicates that the economy would gain, especially in employment terms, from the introduction of greener production systems (see Box 1). It must be noted that technological innovations are typically labour-saving and have often been accompanied by job losses.

After significant restructuring in the last century and increased automation and computerisation in recent years, metals manufacturing is no longer the source of jobs it once was. Business-as-usual (BAU) projections for the steel industry in Europe and the USA suggest job losses of 40,000-120,000 over the next two decades, faced with growing competition from Asia where production costs (wages) are lower. A BAU scenario in a study on climate action by the European Trade Union Confederation (ETUC et al 2007) projected that up to 2030, the de-localisation of 50 to 75 MT of steel outside the EU, or the equivalent of 25-37 per cent of current production, is possible. This would have an impact of 45,000 to 67,000 direct job losses, to which 9,000 to 13,000 outsourced direct jobs are to be added – resulting in a total loss of 54,000 to 80,000 jobs directly related to production. In an alternative scenario, where European authorities and industry were assumed to pursue a low carbon strategy, it is estimated that 50,000 direct jobs, internal and outsourced, could be saved in the European iron and steel industry. This strategy would involve investment in R & D, installing more efficient technologies and applying a tariff on steel imports based on carbon content, thus enabling steel production by low carbon processes to be competitive.

Similarly, the capital intensive aluminium industry cannot be expected to be a major source of green jobs. The same applies to the less labour-intensive cement industry, where the introduction of more energy-efficient plants in major producing countries such as China and India will lead to fewer workers required there as well. In this scenario, greening becomes a critical factor for competitive advantage (delivering low carbon products) and job *retention* rather than job *generation*.

Against this background, secondary production (recycling) therefore becomes a proxy for a greener industry (see UNEP, ILO et al. 2008). This requires appropriate processing equipment and recovery systems, supported by effective government regulations. Japan has largely abandoned domestic primary production and switched to secondary production and imports. In the EU, secondary production of aluminium provided 40 per cent of total output by 2006. The world's largest producer of aluminium, China is increasing its secondary production and faces shortages in availability of scrap metals. In the cases of India and Brazil, which have the highest recovery rate in the world for aluminium cans, endemic poverty is a key factor in driving recycling. This raises the challenge of ensuring decent work in an industry (recycling) where work can be dangerous and unhealthy as well as poorly paid.

Experience from the consumer electronics industry, producing products with increasingly short life-cycles, has shown how a growing problem of e-waste – going to destinations such as China, India, Pakistan and Bangladesh – results in environmental and health problems for both workers and society (owing to heavy metals and organic contaminants ending up in water and the food chain). While recycling is of great value in terms of resource conservation, it can entail dirty, undesirable and even dangerous as well as unhealthy work.

In the metals value-chains, there are significant job-creation opportunities to be found in the use and recycling of valuable byproducts and scraps. Around 21 million tonnes of ferrous slags were recovered from iron and steel mills in the USA in 2005 (van Oss 2006). This provided employment for over 2,600 people. Assuming comparable labour productivities in other countries, extrapolating USA data to other countries suggests that slag recycling worldwide might employ some 25,000 people (UNEP, ILO et al. 2008). Recycling of steel itself saves up to 75 per cent of the energy needed to produce virgin steel. In sectors such as the automotive industry and construction, steel recycling rates can reach up to 100 per cent. Less developed recycling systems and related infrastructure in developing countries result in lower recycling rates. A report by UNIDO (2007) has put the share of secondary (recycled) steel at 4 per cent in India, 10 per cent in China and 25 per cent in Brazil.

In the pulp and paper industry, where modernised and more efficient plants require fewer workers, recycling is the fastest growing source of substitute and new, green employment (UNEP, ILO et al. 2008). Recycling is labour-intensive and creates more jobs than incineration and land filling. This comes in addition to major savings in GHG emissions landfill waste avoided. Paper comprises about a third of all municipal solid waste. Paper waste, growing faster than any other material in countries such as China, is driven by increasing population growth, urbanisation and consumption patterns. For all materials considered here, studies have shown that recycling is preferable to landfills and incineration not only on an environmental basis but also since it creates more jobs. Related regulations on, for example, packaging will also impact job creation in the recycling industry.

Box 1: Steel production with higher components of recycled materials. Direct and indirect impacts on jobs. Estimation for the EU27

In a 2007 study (CEC 2007), GHK Consultants evaluated the economic significance of the environment in terms of employment, output and value added associated with the range of activities that make use of, or contribute to, environmental resources in the EU27. Input-output tables for each Member State were used to estimate the indirect and hence **total economic impacts** of defined activities that are linked to environmental resources. The study also considered policy interventions directed to improve resource efficiency. One of the policy scenarios examined assumes a switch of 10 per cent by value in raw material inputs to steel production from virgin materials to recycled materials. As a result of the intervention, positive total impacts are reported for output and employment. The results are summarised in the table below.

The initial direct impact is neutral as the reduction in output from one sector is met by an increase in output from another sector. However, the net indirect (including induced) impact of this substitution leads to an increase in output of nearly €197 million and an extra 1,781 jobs. Adding the direct and indirect effects indicates that this substitution would add €197 million of output and 3,641 (1,860 direct and 1,781 indirect) jobs.

The net positive impact on jobs and output is mainly owing to the supply-chain effect of the recycled materials sector. The recycled materials sector uses inputs from many other sectors, thus creating more jobs and wealth. If the substitution were to lead to an increase in the costs to the steel sector – since inputs of recycled materials cost more than virgin materials – this would be reflected in the cost of steel and paid by users of steel. Output and profits of the steel sector would be expected to fall due to higher costs of steel products. The ability to pass costs on to users will depend on factors such as the price elasticity of demand for steel. According to parameters of the model used, the steel sector could pass on 45 per cent of its unit costs to its customers and would have to absorb the rest as reduced profits.

	Output (million Euros)	Jobs (FTE)
Direct impacts		
Virgin material sector: loss of output and jobs	-489.0	-4,092.0
Recycled material sector: gain in output jobs	489.0	5,952.0
Net direct impact (1)	0.0	1,860.0
Indirect impacts		
Virgin material sector: fall in demand for inputs and subsequent fall in output from suppliers to the virgin material	-83.0	-753.0
Recycled materials sector: Increase in demand for inputs and subsequential increase in demand from various sectors	280.0	2,534.0
Net direct impact (2)	197	1,781.0
Total impact (3)=(1)+(2)	197.0	3,641.0

Industries such as steel and aluminium can expect growing demand from new markets in the form of "clean-tech" such as solar technologies, being an important source of materials and components required for these. These potentials can be identified by considering industries not in isolation, but as part of a broader value chain that contains possible hidden economic opportunities. Following this approach, a study by Gereffi et al. (2008) in the USA shows the example of how solar manufacturing can replace jobs lost in automotive manufacturing. Infinia Corporation has developed a concentrating solar-dish system specifically designed to be mass-produced by Tier 1 and Tier 2 auto manufacturers in the USA. Infinia included USA auto suppliers from the very beginning in product development and design. The product can be manufactured on existing auto production lines which have high surplus production capacity. Infinia estimates each unit of auto production capacity can be retooled to produce 10 units of their Solar Power System, producing 120,000 MW of solar capacity and securing as many as 500,000 manufacturing jobs. In cases like these, where certain jobs are potentially replaced with jobs in another sector, calls have emerged for a "fair and just transition" in which those harmed by the changes are adequately assisted and the new opportunities created shared by specific groups of worker constituencies.

As suggested by the USA auto industry case, creating new job opportunities may lie in the introduction of new technologies, looking beyond just efficiency improvements, and considering possibilities that lie in diversification and in the value chains that provide green technologies such as solar and wind power. The IEA estimates that for every billion US dollars invested in clean-energy technology, there will be a creation of 30,000 new jobs. As indicated by Martinez-Fernandez et al. (2010) these figures must be dealt with cautiously, not ignoring job losses and social stress that will go with a period of transition.

Remanufacturing and recycling of scarce metals provide primary opportunities in the manufacturing sector *per se*. Significant opportunities may also lie in the area of "industrial symbiosis" (new products from old processes), highlighting also the importance of broader systemic (cross-sectoral) impacts as considered in the modelling (see next section) done for this report. Public policies (such as extended producer responsibility or returnable deposits) can help to promote closed cycle manufacturing and extend product life cycles, thereby saving resources and creating more jobs in maintenance, repair, remanufacturing and recycling. Collection and sorting of used or end-of-life products (reverse logistics) could be a significant employer. Shifting taxes away from labour on to waste emissions and/or materials extraction could also be an effective way of creating more jobs by cutting labour costs *vis a vis* direct energy costs, or capital costs.

4.4 Growth and rebound – lessons for developing markets

The eventual advent of "peak oil" means that the supply of cheap oil and gas cannot be expected to continue in the future. Future economic growth will depend more than in the past on technological progress and capital deepening because growth in the world labour force is projected to slow gradually. The rate of energy efficiency increase has been slowing down since the 1960s. An acceleration of technological progress *vis-a-vis* resource efficiency seems possible, but it is unlikely to happen without an unprecedented global effort.

Future economic growth is expected to be driven by emerging countries, led by China and India. But they are expected to shift away from their current emphasis on export-oriented growth to more domestic demand-driven growth, as growth of the labour force and rural-urban migration slows leading to wage increases; and as social safety nets are put in place or strengthened. Increased consumption relative to savings will reduce global imbalances, but their GDP growth rates will also slow. The greatest resource-efficiency effort is required in the weaker developing country economies where most of the population increase will take place, and where the economic and social impacts of resource scarcity and commodity price volatility will probably be most severe (Shin 2004).

Economic growth is evidently the primary means of reducing global poverty, although it has a less direct impact on inequality. Increased demand from urbanising populations for products and services and productivity growth will be the basic drivers of economic growth. Increased resource efficiency can be expected to explain part of the future growth in productivity. This is the reason why some point to a likely "rebound effect" – usually on the basis of historical examples and evidence of the "Jevons paradox" – and question the extent to which investment in efficiency will really cut resource use. There is little doubt that technological innovations – by increasing efficiency, cutting the cost of basic materials and energy, and by increasing labour productivity – have been the main drivers of economic growth in the past. Lower cost of inputs generates increased demand for existing goods or for *new* products and services that did not exist previously.

There is not just one rebound channel or mechanism but several, which include: more intensive use of energy-consuming equipment by current users because of a higher energy efficiency and thus a lower effective energy cost; purchase of larger units or units with more energy-consuming functions/services and consequently more energy use (e.g. vehicles with air-conditioning); more energy- and resource-efficient technologies diffuse to new sectors and applications (including households), which partly undoes savings resulting from per-unit improved efficiency; re-spending of money savings owing to energy conservation on other energy-intensive goods and services (income effect); creation of new demand (i.e. new users) owing to a lower market price of energy if initial energy savings are large; and diffusion of more energy-efficient general purpose technologies such as batteries or computers (cf Van den Bergh, 2008, 2011). These examples all depend ultimately upon price or cost reductions owing to efficiency gains. However, the next few decades are almost certainly going to experience significant energy price increases once the costs of CO_2 abatement have been set at levels sufficiently high to stabilise atmospheric CO_2 and have been fully internalised to users. In this case, greater take-up of more efficient technologies will help to abate the otherwise negative impacts on economic growth resulting from higher energy prices. Yet, energy-efficiency proposals cannot rely on higher oil prices as such, with among others, alternatives such as coal available. This reality underlines the need to have appropriate regulatory policies in place.

5 Quantifying the implications of greening

5.1 Business-as-usual trends

Summarising findings from the Millennium Institute's T21 model for investment scenarios up to 2050, we start with business-as-usual (BAU) in manufacturing. The IEA projects that under all scenarios, GDP will quadruple between 2010 and 2050[9] and manufacturing (as defined for purposes of this chapter) will contribute 27.6 per cent of GDP and 24.2 per cent of global employment in 2050. Yet, if "peak oil" occurs sooner than the IEA assumes, the global economic growth rate may be much lower than foreseen by the IEA (2009).

Heavily relying on energy, manufacturing industries account for one-third of global energy use and 25 per cent (6.7 Gt) of total world emissions, 30 per cent of which comes from the iron and steel industry, 27 per cent from non-metallic minerals (mainly cement) and 16 per cent from chemicals and petrochemicals production. CO_2 emissions from fossil-fuel combustion in the industrial sector totalled 3.8 Gt in 2007, a 30 per cent increase since 1970. They are projected to continue increasing to reach 5.7 Gt in 2030 and 7.3 Gt in 2050 in the BAU case, primarily owing to increased consumption of coal.

The amount of water withdrawal for industrial production is expected to increase from 203 km3 in 1970 to 1,465 km3 in 2030 and 2,084 km3 in 2050. Industrial water as a share of total water demand is expected to increase from 9.4 per cent in 1970 to 22 in 2030 and 25.6 per cent by 2050.

5.2 Trends under a green investment scenario

The Millennium Institute's T21 model uses IEA estimates selectively (among others) to simulate what the economy-wide effect of investments in the greening of sectors would be, using indicators such as industrial production and GDP growth, employment, resource consumption, and CO_2 from fossil-fuel use (cf Figure 8). These results are presented in this section, covering six industry sub-sectors: steel, textile aluminium, leather, paper and pulp, and chemical and plastics products. Other industrial sectors are covered in the broader and aggregated industrial macro sector, presented in the modelling chapter. Energy intensive industries such as cement, the non-metallic mineral products and electrical and electronic products sub-sectors are not disaggregated in the model owing to lack of data.

In the T21 green economy model, the "green" investment scenario G2 in the industry sector assumes the allocation of 3 per cent of the total additional green investment[10] to improvements in industrial energy efficiency. This translates into US$79 billion per year on average between 2010 and 2050. Investments are allocated to both the broader industrial sector and to the selected subsectors) in more efficient, low carbon, development.[11] Faster growth, all else being equal, translates into higher demand for basic materials, resulting in higher energy demand and generation of greater CO_2 emissions in the industrial sectors.

Results of the simulation indicate that investing in the industry sector reduces energy consumption and emissions. This, in turn (other things being equal) helps to reduce the price of fossil fuels and yields higher value-added and employment (both within the industrial sectors analysed and across the economy). The total industrial employment is projected to be about 1.09 in the G2 scenario (24 per cent of overall employment across all sectors) in 2050, 9 million lower than in BAU2. Concerning employment in the six manufacturing sectors analysed in more detail, the total number of jobs is 109 Mn in the G2 scenario in 2050, 15 million more than in BAU2 (see Figure 9). The change (net reduction) in total employment is driven by the interaction of several factors: (1) higher demand for the industries analysed – increasing employment (the dominating factor making employment rise in the energy intensive sectors studied in more detail), (2) higher efficiency and capital intensity (as opposed to

9. The IEA economic model is typical of neo-classical growth models, in assuming that growth can and will continue at historical rates regardless of the availability or price of energy. This assumption has been strongly challenged by the econometric work of Ayres and Warr (Ayres, Ayres and Warr 2004, 2009a), who argue that growth is actually proportional to the output of "useful work" by the economy as a whole. Useful work is the product of energy consumption times conversion efficiency.

10. Additional Green economy investments worth 2 per cent of GDP for G2.

11. This investment is estimated using the industrial CO_2 abatement cost published by the IEA in the WEO 2009 but with limited investment in CCS. See Modelling chapter.

labor intensity, also due to the fact that running capital is cheaper in G2, for instance due to lower energy costs) – reducing employment, (3) higher productivity of work (driven by higher life expectancy and access to social services in G2). However, (4) our calculation does not include potential employment creation from energy efficiency improvements (which is the case for end-use in the residential and commercial sectors), due to the lack of relevant literature.

The green investment will lead to a considerable energy efficiency improvement by 2050, practically decoupling energy use and economic growth, particularly in the most energy-intensive industries. The improved energy efficiency is projected to mitigate total energy and process-related CO_2 emissions in the industrial sector by 51 per cent (3.7 Gt in the G2 case) by 2050, curbing the trend of growth as of 2025. Total emissions from the six selected manufacturing sectors also decline to 1.3 Gt in the green case, from 2.7 Gt in the brown alternative (BAU 2) – (see Figure 10).

At the industry level, the avoided energy consumption averages 52 per cent by 2050 – comparing G2 to BAU2 – (or 52 per cent relative to BAU2), resulting in avoided costs of up to US$193 billion relative to BAU 2 per year, on average, between 2010 and 2050 depending on the industry considered[12]. The chemical and plastics sector provides the greatest opportunity, with a potential of US$193 billion relative to BAU2 in yearly avoided energy costs. Steel follows with an average US$115-136 billion potential savings per year. Paper and pulp saves US$37 billion, textiles US$17 billion and leather US$8 billion. Aluminium is the least promising, with US$4-4 billion of yearly avoided energy cost in the G2 case. The above estimates are only proposed as examples, based on an assumed investment of US$37.6 billion per year on average between 2011 and 2050 (see Figure 11).

The model also assumes the same cost per ton of emissions abatement for all industries, although in reality they rely on very different technologies. But the G2 model runs provide some insight into the aggregated potential opportunity cost of investment in low carbon technologies and efficiency improvements.

The average total cost of emissions in the BAU and green economy scenarios (based on IEA projections) would be US$629 billion (BAU2) and US$380 billion (G2). Assuming an emissions cap-and-trade mechanism with carbon prices aligned with the recent US domestic proposal, and no free allowances, the green economy investment would yield US$264-US$249 billion per year

12. Avoided costs are not pure economic gain, since they imply disinvestment and disemployment in the traditional energy sectors (the inverse of rebound).

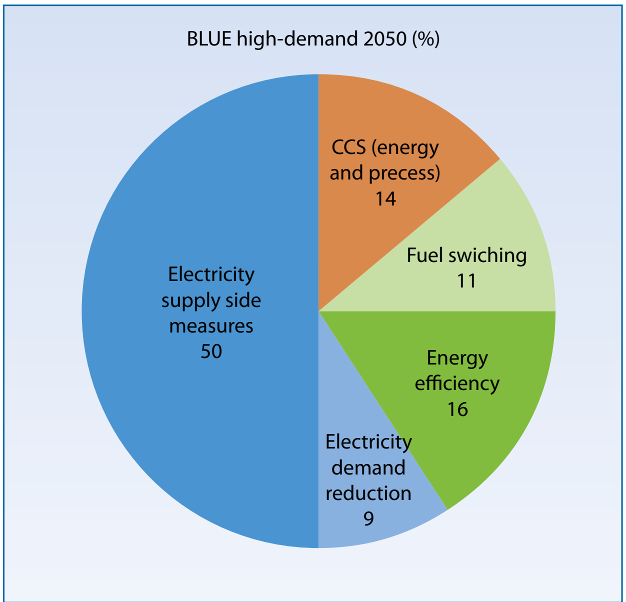

Figure 8: Contribution to CO_2 reductions from industry per type of measure – IEA model (2009b)
Adapted from: Tukker and Tischner (2009)

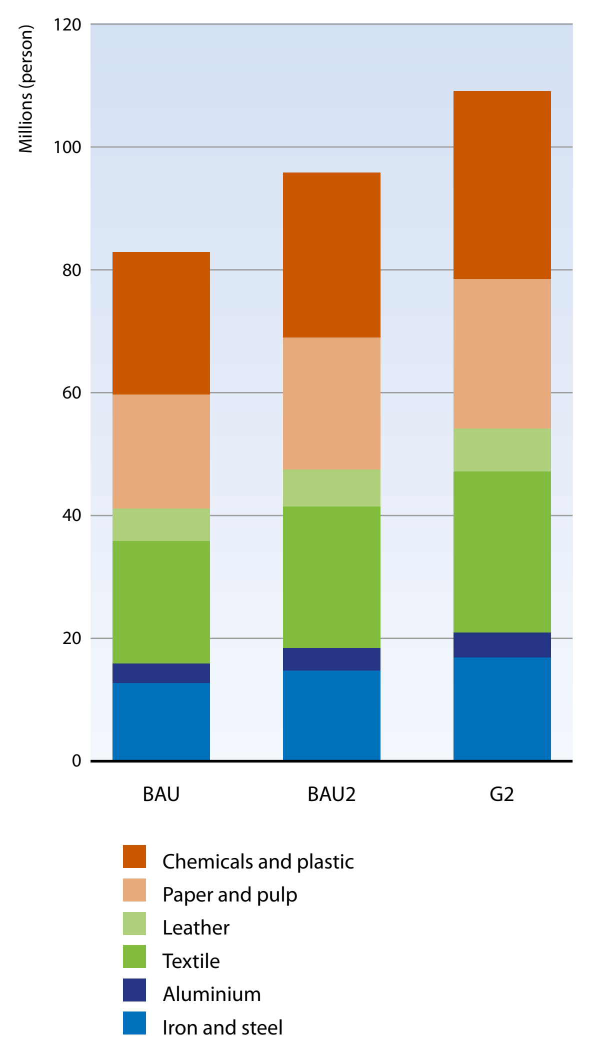

Figure 9: Employment per manufacturing sectors by 2050 in G2 and BAU scenarios (person per year)
Source: IEA (2009)

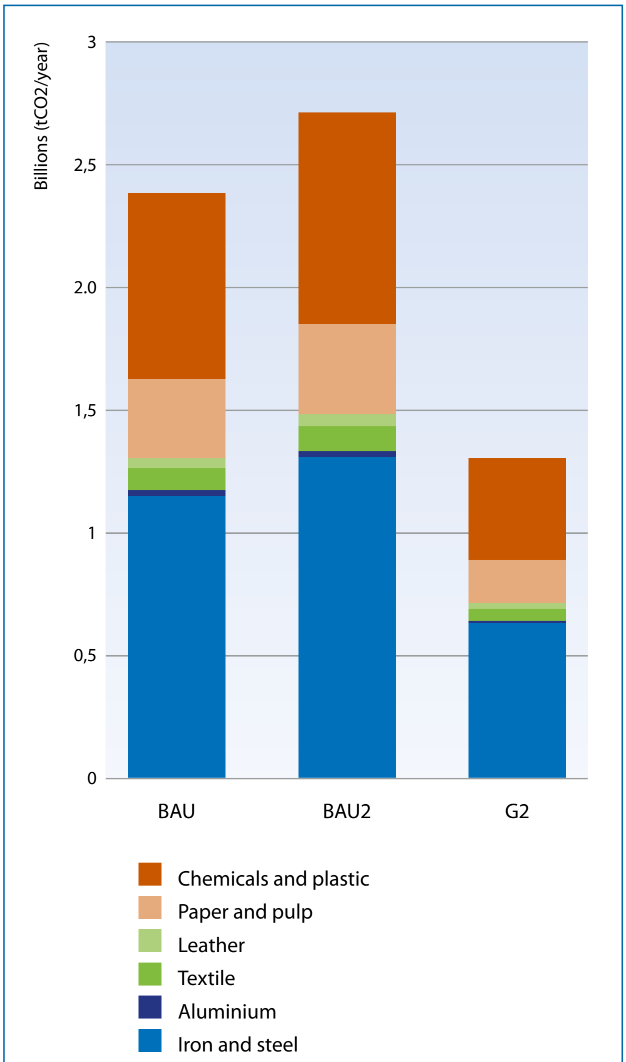

Figure10: Energy-related CO_2 emissions per manufacturing sector by 2050 in G2 and BAU (tCO_2/year)
Source: IEA (2009)

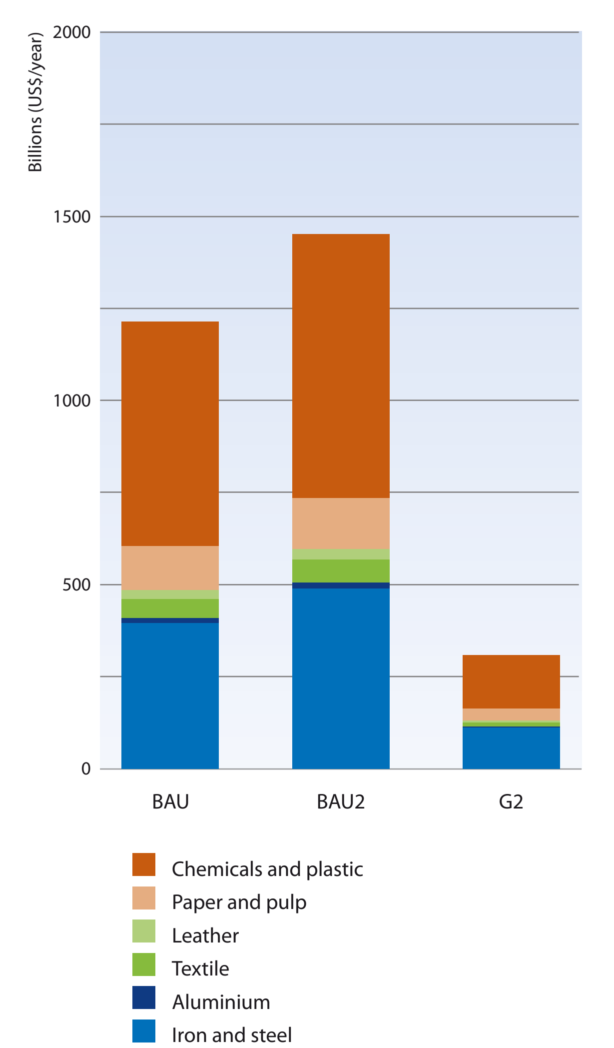

Figure11: Energy costs per manufacturing sector by 2050 in G2 and BAU scenarios (US$/year)
Source: IEA (2009)

on average between 2011 and 2050 in avoided costs relative to corresponding brown scenarios (or US$230-US$195 billion from the BAU case).

It is worth repeating that the necessary simplifications in the model (indeed, any model) result in simulated outcomes that may be quite different from reality, inasmuch as they are unable to take into account a variety of cause-effect chains unrelated to the assumed investment-growth-employment relationships. However, the optimistic results of the simulation are realistic, at least in magnitude. The existing global economic system, and especially its industrial component, has been built upon a base of under-priced fossil energy and other ecosystem services. This has enabled grossly wasteful production and consumption practices in many parts of the world. For several reasons, the price of energy is probably going to rise significantly in the future. This will induce everyone in the system to seek energy-conserving products and services. The ultimate effect will be to enable existing goods and services to be produced with much less energy. Whether increased efficiency will fully compensate for higher costs (thus permitting the same amount of economic growth or more) remains to be seen in practice, but a "double dividend" potential may well exist and is illustrated in the G1 and G2 scenarios.

Recent analysis for the USA provided an assessment of the economic impact of the climate-energy legislation (APA-ACELA) pending in the USA, together with a version with enhanced energy efficiency features, as compared to the "reference forecast ("business-as-usual") in the 2010 International Energy Outlook published by the Energy Information Administration (US, DOE). It covers the period 2013-2030. Its results tend to confirm that the results by the Millennium Institute reported here, especially as regards employment, are in the right direction.

6 Enabling conditions for a green transformation in manufacturing

The manufacturing sector can make a significant contribution in greening national economies, by producing goods that are more resource-efficient and have lower environmental impacts over their life-cycles. This applies in particular to the highly resource-intensive value chains such as that of metals and car manufacturing. But for the manufacturing industries to make this transition, they need to receive the appropriate policy and price signals. Under certain conditions it also needs institutional support from governments, in particular for ensuring that supportive investments in physical infrastructure and education are sufficient to enable a transition that requires new systems and skills.

The past several decades have witnessed a major restructuring of the global economy, with the global manufacturing industry base shifting toward developing countries and emerging economies, and the developed countries becoming ever more service-oriented. Globalisation through increased cross-boundary trade and investment flows is driving this restructuring, along with technological and associated organisational changes. This transition process, driven by global factors of production and markets rather than local development factors, has resulted in significant capacity gaps in developing and transition economies in managing the structural transformation of their economy on a more sustainable basis. This situation is a handicap for small enterprises to adopt more resource efficient technologies as they face growing demand to meet the new standards required to market their products through global supply chains.

With this background in mind, this section on enabling conditions focuses on actions that mainly governments can take to help induce the transition to green industrial production both through incremental and transformational changes. It is a transition that faces drivers such as resource scarcities and rising energy costs as well as barriers such as inefficient monopolies, outdated regulations that restrict new technological approaches and principle-agent conflicts. It is a transition in which, for example, power monopolies need to be challenged by government support for decentralised energy production and investment in smart grids that saves electricity transmission losses. It is also a transition in which governments need to consider the integrated resource efficiency perspective, avoiding technology policies (cf the example of Carbon Capture and Storage) that focus on a single measure (such as carbon emissions) at the cost of increased fossil fuel extraction, lower resource-efficiency and lower economic growth.

Before reflecting on appropriate instruments for action, two key policy priorities for greening manufacturing are recommended: (i) the promotion of closed cycle manufacturing and related life cycle approaches with supportive recovery and recycling infrastructure, and (ii) regulatory reform to enable factor efficiency improvements in energy use, for example through the introduction of co-generation and combined heat and power (CHP) technologies and the feed-in of decentralised power generated by use of renewables. The latter needs to be supported by investment in smart grids and approaches such as feed-in tariffs and time-of-day pricing (see Energy chapter).

6.1 Policy priorities

Closed-cycle manufacturing and life cycle approaches

Efforts to promote resource efficiency at the product, production process and company level need to be complemented by resource-efficiency innovations at the industrial cluster and systems level. At the company level, this starts with approaches such as eco-design, life-cycle management and cleaner production. At the industry and systems level, this implies innovations such as the greening of supply chains and clustering of industries in a given economic zone to become a platform for resource efficiency through optimised resource flows between industries. The industrial parks of the future could be "eco-parks" to maximise industrial symbiosis and secure green jobs.

The move toward a closed-cycle manufacturing through remanufacturing and reprocessing of post-consumption products and materials that are currently thrown away as a waste, represents an important opportunity for the transition toward a green economy. Two broad categories of post-consumption waste that could be the focus in such a transition are (i) e-waste and (ii) materials such as metals, glass, plastics and paper products. The latter category constitutes the most diverse group of industrial products, which are already a target of some degree of recycling, albeit in varying degree of organisation and with an informal character in many developing societies. The policy focus would thus be on formalising and structuring the waste recovery and recycling process in such a way that it will bring added economic, environmental and social benefits. In the case of e-waste, this implies a high-tech value chain where the production of electronic goods is done by multinational companies in developed and emerging economies. It is a value chain with labour-intensive disassembling work required for the recovering useful parts. The combination of these features could also serve as a basis for the evolution of a different form of symbiosis involving economic actors from developed and developing markets.

Co-generation: combined heat and power

Most industrial applications have a need for heat, and most of the potential for co-generation applications can be found in energy-intensive industry sectors such as steel, aluminium, cement, chemicals, pulp and paper. It is technically and economically feasible to "recycle" high-temperature waste heat or other combustible wastes from industrial enterprises such as coke ovens, steel mills, cement plants, glass producers, brick and ceramic works. This provides the opportunity, should policy and regulation allow, to complement centrally-generated electricity networks with local heat and power systems where electricity is generated and heat re-used at the local industrial site level. It is an opportunity for significant factor-improvements in resource productivity, combined with investment in smart grids.

The world is undoubtedly electrifying, and demand for electric power continues to grow in every part of the world. Numerous industrial, commercial, and domestic users consume fossil fuel simply for purposes of cooking, hot water, heating air for space-heating, or producing industrial steam at moderate temperatures. There is no technical reason why most of these applications of low-temperature heat could not be supplied by means of small co-generation (CHP) facilities, based on diesel engines, small gas turbines, high-temperature fuel cells or even rooftop solar collectors. Small CHP systems remain a largely untapped market (Von Weizsaecker et al. 2009). Furthermore, a number of industry sectors have significant potential for generating electricity from waste heat, as in the case of steel mills.

In order to make effective use of such possibilities, it would be necessary for all of these electricity-producing units to be connected to the grid, both to sell their surplus and to buy during occasional periods of breakdown. However, in most countries the electric power industry is a legal monopoly, whether public or private, with exclusive rights of distribution. Besides the natural tendency of inducing inefficiencies across the whole chain of production, distribution and use, such monopolies are acting as major institutional barriers for the development of CHP facilities at different scales. The primary problem faced by would-be CHP investors, according to the IEA (2009b), is the difficulty in securing a fair market value for any electricity that is exported to the grid. Overcoming these barriers requires policy measures that encourage innovative technologies such as CHP, applied to industrial waste heat and waste biomass in particular.

6.2 Policy instruments to enable green manufacturing

The spectrum of instruments available to governmental institutions to shape the enabling environment for greening industry and manufacturing can be categorised as follows:

- regulatory and control mechanisms;
- economic or market-based instruments;
- fiscal instruments and incentives; and
- voluntary action, information and capacity building.

Regulatory and control mechanisms

The major sources of significant quantities of emissions and effluents in manufacturing industries have traditionally been the initial targets for regulatory and control instruments. Legislation with clearly defined standards of technology and/or performance can drive green investment, encouraging industries to use natural resources more efficiently and create markets for green products and production. Regulatory requirements can build in cleaner technology standards in the licensing of new industrial operations. It can establish emission and discharge standards for industries with clear requirements for the best available or best possible technology (BAT, BPT). However, care needs to be taken that setting standards by regulation does not impede innovation and fail to keep pace with technological progress. Experience in China has shown how eco-industrial development or industrial symbiosis can be held back by regulations that enforce too low fines on discharges and in addition forbid or limit the exchange of by-products between companies (Geng et al. 2006).

Licensing of operations provides an opportunity to provide incentives, for example related to land-use planning, to encourage existing industrial estates and parks to move toward a more closed-loop manufacturing paradigm through materials recycling and exchange schemes. Policy and planning provisions can be used to ensure that the development and management of new industrial parks and estates are in accordance with the principles of industrial symbiosis and turn them into eco-industrial parks. This also requires governments to invest in supportive infrastructure for waste treatment and the conversion of wastes into resources. In addition, quota systems for resource (e.g. water) use can be set up in industrial parks, with a penalty mechanism that requires tenants to pay several times the normal rate for those resources they use whenever they exceed their allotted quota.

Regulatory and control mechanisms can promote principles such as Prevention (cf 3P, 3R), Polluter Pays and Extended Producer Responsibility (EPR) to encourage large manufacturers with complicated supply chains to favour closed-cycle manufacturing and more efficient "take back" systems for remanufacturing and recycling. In recent years, regulations such as the Waste Electrical and Electronic Equipment (WEEE), Restriction of Hazardous Substances (RoHS), and Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) directives of the EU have had impact world-wide on standards applied in the manufacturing and use of products.

Traditional command and control regulations introduced in many countries since the 1970s have tended to be technology-based or performance-based. They focused on "end of pipe" solutions, not considering more preventative approaches and ways to improve resource efficiency through more systemic changes to the production process or even product design. This left limited incentive for manufacturers to continually and fundamentally improve standards (dynamic efficiency), as opposed to economic instruments that put a price on emissions and effluents to create a permanent incentive for improvement. Whilst appearing simple to introduce, command and control regulations can be costly and inefficient in use.

The historical example of vehicle manufacturing shows how regulatory and control approaches can be combined with fiscal and voluntary instruments to bring about shifts in technological innovation. Mandatory or voluntary standards and taxes can drive shifts in innovation *along* a technology frontier or shifts *of* the frontier (OECD 2010b). The types of changes described for the manufacturing industry in this chapter also require a shift *of* frontier, including redesign of products and the introduction of new production systems for closed-loop manufacturing. However, changes along the frontier for continual improvement remain important. In the case of vehicle manufacturing, these can involve innovation in end-of-pipe emission abatement, input substitution (e.g. of fuels), factor substitution (more efficient, redesigned engines) and output substitution (greater fuel efficiency of a redesigned vehicle). Analysis of invention and patents in car manufacturing over the period 1965-2005 by the OECD (2010b) has shown a strong positive effect of petrol taxes – combined with regulatory pressure – on engine redesign technologies, with factor-substitution showing the highest growth in patent applications over the period considered.

Economic or market-based instruments

Economic instruments for pollution control and reducing other environmental pressures include charges and fees for non-compliance, liability payments as well as tradable permit systems targeting, for example, air pollution, water quality and land management. Instruments regulating the price have the advantage of ensuring that the marginal cost of abatement is equalised among all polluters. Charges can target emissions and products (at the level of manufacturing, use or disposal), as well as byproducts such as packaging and batteries. The latter has also been addressed through deposit-refund systems, which can become of increasing significance world-wide for industries such as electronics and car manufacturing. New legislation can encourage recycling by mandating returnable deposits on recyclable products. Direct regulation on emissions can usefully be complemented by returnable deposit rules and end-of-life disposal rules.

To promote integrated water resources management amongst industrial water users, the Government can either (a) establish prices through taxes, fees and royalties or (b) limit quantities through tradable permit schemes. In the case of the latter, a market for water use in a shared river basin can allow users with relatively high-valued water uses to purchase or lease water from users with relatively low-valued water uses. Similar to air- pollution credit schemes, the aim is to transfer reduction responsibilities to agents with the lowest costs of use reduction. In the USA, markets have been created in arid states to allocate water with relative success. Canada is an example of an industrialised country where power production and manufacturing are the principle water-using sectors. Most of the water used by manufacturing plants has traditionally been discharged directly into a receiving water body. Examination by Renzetti (2005) of the use of economic instruments for integrated water resource management (IWRM) in Canada has shown that the use of economic instruments can reduce monitoring costs, but designing them properly and setting them at appropriate levels requires that federal and provincial environmental regulators use economic analysis (such as cost-benefit or cost-effectiveness analysis).

In regulating acid-rain emissions, the USA was a pioneer in introducing an emission-trading scheme to reduce SO_2 and NO_x emissions (1990 Clean Air Act), whilst the EU introduced a regulatory approach through its Large

	Aluminium	Steel	Cement	Chemicals
Share in GHG emissions	0.8 % of global emissions and 4% of manufacturing industries' emissions	3.2 % of all global emissions and an estimated 4.1% of global CO_2 emissions; approx. 15% of all manufacturing emissions – with 70% of emissions from direct fuel use and 30% emissions indirectly from electricity and heat	4 % of global emissions (process emissions and energy use) and 5% global CO_2 – this is expected to double in the next 40 years, most of the increase in developing countries; 18% of all manufacturing emissions, emitted at various points in the production process	5% of global emissions. and 23% of emissions associated with manufacturing and construction industries
Concentration of actors	Twelve countries represent 82% global production; China, Russia, the EU, Canada and the US account for 61% of total production; ten leading companies (mostly multinationals) produce 55% of world's aluminium.	Around 90% of total steel-making GHG emissions is produced by nine countries or regions. The top 25 steel-making companies collectively accounted for approx 43% of global production in 2006.	Relatively low concentration, with the 16 largest companies accounting for around 25% of global output. About 81% of production takes place in 12 countries; China alone produces around half of the world's cement.	Highly concentrated geographically – the EU, US, Japan and China account for 75% of global chemical production. Diversity of products means that overall there is a low concentration of actors in this subsector; small and medium-sized enterprises are common.

Table 7: Greenhouse gas emissions and structure of major manufacturing industries
Source: UNEP (2009), WRI (2007)

Combustion Plant Directive (1989). In 2005, the EU activated the first region-wide emissions trading scheme (a cap-and-trade system) to meet its Kyoto commitments under the climate change convention (UNFCCC). The scheme has shown the complications regulators face in introducing emission trading schemes through either "grandfathering" (free allocation based on existing emissions by industries) or auctioning. Whilst initial over-allocation in the EU ETS resulted in a zero-carbon price, allocation rather than auctioning would tend to be preferred by heavy industries such as aluminium and steel that face direct international competition. Compared to command-and-control instruments such as licensing and technology standards, emissions trading can perform better in terms of criteria such as cost-effectiveness, long-term effects and dynamic efficiency, i.e., promoting ongoing improvement. Experience in the climate field has shown that the cost-effectiveness of trading systems can be determined by the visibility and robustness of the goal and the system, the effectiveness of the carbon price and the effectiveness of the constraint (Buchner et al. 2009).

Manufacturing industries based in developing countries can be introduced to credit and trading schemes through industry sector initiatives and project-based activities such as the Clean Development Mechanism (CDM) under the UNFCCC. Provided that procedures under the CDM or similar type mechanisms are streamlined to reduce transaction costs, it can provide a promising avenue for greening manufacturing in developing countries. By 2010, many CDM projects involved investment in renewable energy technologies but a much smaller number involved investment in energy efficiency and fuel switching. These are important areas for transformative investments in manufacturing, ones where real opportunities can be taken if technology standards are to be applied with reference not only to individual projects but also industry sector-wide best practice.

Sectoral approaches to climate action have received considerable attention as second best option (as opposed to global cap and trade) for introducing economic instruments and policies to reduce GHG emissions, in particular implying manufacturing industries world-wide. Economic factors to consider in the introduction of sector approaches in developing countries include the following (UNEP 2009):

- the nature of the adjustment costs associated with reducing emissions;
- the potential for avoiding capital lock-in;
- the nature of technical capacity within specific sectors and countries; and
- the availability of access to appropriate data and technology.

Some have argued (e.g. Bodansky, 2007) that a few industry sectors stand out as ideal candidates for climate initiatives—being large, homogenous, highly concentrated and highly competitive (cf Table 7). These include aluminium, steel, cement, transport and power generation. The cement industry, although also relatively homogenous and highly concentrated among countries, includes many smaller producers and is less subject to competitiveness issues than aluminium and steel. Emission targets could be defined for a given sector, with emissions allowances being allocated to individual emitters within that sector, and with trading allowed between countries participating in the agreement and/or with countries with economy-wide or other sectoral targets. Even if not introduced at international level, the debate on sector approaches provides important lessons for developing country governments in introducing climate policies with competitive, high impact industries in a step-by-step manner. This is particularly important to industrialising countries that host major emitting industries discussed in this chapter, notably China, India, Brazil, South Africa, Indonesia, Thailand, Chile, Argentina and Venezuela. The analysis of using market instruments through sector approaches also shows the flaws of introducing approaches that target only high emitting industries on a sector basis, as opposed to full value chains of supply and demand with these and other industries implied.

Fiscal instruments and incentives

Fiscal policy, comprising public expenditure, subsidies and taxation, can provide powerful incentives that alter the basic cost-benefit calculation of producers and consumers, thus driving change in behavior from business-as-usual. Taxes are unrequited in the sense that the benefits provided by government to taxpayers in exchange are not necessarily in proportion to their payments. Tax exemptions can be made for specific products or industry sectors. Tax revenues can be earmarked for a specific purpose, which may or may not relate to the field of activity that was taxed in the first place. An example would be a tax on landfills or plastic bags, the revenues of which is used for waste management infrastructure or other purposes. By 2009, the Government of South Africa was expecting revenue of USD 2.2 million from its plastic bag levy (see case study Box 2), income that was due, among others, to support the development of the local waste management industry. In 2010, the Government of India announced a carbon tax on coal production, from which it was expecting to raise US$535 million and planning to use the revenue for investment in clean energy (Pearson 2010). Historical research by the OECD has found that most of the taxes identified in member countries were levied on a specific tax base related to energy, transport and waste management. In its latest survey, the OECD (2010a) noted that taxes levied closer to the actual source of pollution (e.g. taxes on CO_2 emissions versus taxes on motor vehicles) leave a greater range of possibilities for innovation, mindful of complications where sources are dispersed and varied.

By the end of the 1990s, the OECD (1999) noted from a survey of its members an increasing use of environment-related taxes for pollution control, raising revenues of up to 3 per cent of GDP and a growing percentage of overall tax revenues. A decade later, the OECD (2010a) confirmed a growing movement towards environmentally related taxation and tradable permits in OECD economies, underlining the value of green taxes to boost innovation as evidenced by the increased investment in R&D and registration of patents on new, cleaner technologies. In 2010, the OECD also reported that revenue from environmentally-related taxation has been gradually decreasing over the past decade relative to both GDP and total tax revenue. This trend is driven mainly by motor-fuel taxes, which still accounted for the vast majority of environmentally-related tax revenue. In many countries, these have increased fuel prices to sufficiently high levels to have greatly moderated the demand for motor fuels. It did foresee that additional revenue from carbon taxes and from the auctioning of tradable permits may increase the role of environmentally related taxation in government budgets.

Stimulus packages introduced by governments following the global financial crisis have included new subsidies for greening industry and cleaner technologies. In addition to its total stimulus package of US$586 billion, of which an expected 34 per cent was devoted to green investments, China announced solar subsidies to help local manufacturers who face a drop in international demand. The car industry world-wide has benefitted from billions of US dollars of emergency bail-out loans, scrappage subsidies and consumer subsidies. In China, the world's largest car market today, the Ministry of Finance announced that it would offer substantial subsidies for the purchase of green cars and financing for the construction, in five cities, of the infrastructure for charging cars with electric power (Waldmeir, *Financial Times*, 2 June 2010). It would offer up to Rmb50,000 (US$7,300) in subsidies for the purchase of plug-in hybrid electric vehicles and Rmb60,000 for pure electric vehicles in cities such as Shanghai. The level of subsidy would be reduced after carmakers sold 50,000 green cars.

The subsidisation of green cars raises questions about its relative priority compared with public transport vehicles and systems. A range of historical subsidies have prevented transformative investments in manufacturing since fuel prices did not reflect the cost of externalities and they resulted in a perverse principle of "the polluter being paid". Greening industry therefore also needs to involve the abolishment of perverse direct and indirect subsidies on resource use that allow favored groups access to free water, free use of the environment for purposes of waste disposal, or cheap electricity and fossil fuels well below regular market prices. It is increasingly important to reflect the full economic and social costs of such use. Where this is politically impossible or otherwise infeasible, a distant second-best solution is to allow accelerated depreciation and relatively low taxes on investments in renewably energy and resource-efficient technologies. As a rule, subsidies should really only be used in case of the clear existence of positive externalities and possibly in support of infant industries.

Green manufacturing can also be supported by *financial instruments* such as revolving funds, green funds,

Box 2: Taxing plastic bags in an emerging market: The case of South Africa

Plastic bags have attracted increasing environmental concern over the last decade, visibly known for their role in littering roadsides, clogging sewer drains, and getting ingested by animals and marine life. A number of countries have started to tax their usage or ban plastic bags. At a time when China decided to ban free plastic bags in 2008, the Worldwatch Institute reported that people in China used up to 3 billion plastic bags daily and disposed of more than 3 million tons of them annually. It signalled estimates that China refines nearly 5 million tons (37 million barrels) of crude oil each year to make plastics used for packaging.

In 2003, South Africa became one of the first countries to introduce a plastic bag levy that targets consumers directly. It addressed the thin plastic bags with handles typically distributed in retail outlets. The regulation tabled under the Environmental Conservation Act noted that the bags are indiscriminately dumped and not collected because the thin plastic film they are made of has little commercial value. It added that the problem is severe in low-income areas where waste collection services are inadequate. Since 2003, shoppers have to provide their own bags or pay for thicker, recyclable bags. Consumers wanting more information or report retailers who are not in compliance have the option of dialing a hotline number run by the Department of Environmental Affairs. Consumers could re-use the thicker plastic bags, paying up to 25 cents for the 10-litre plastic bag, 31 cents for the 12-litre bag and 49 cents for the 24-litre bag. The thickness of the bag was lowered in a compromise agreement with industry. Some retailers agreed to lower food prices in order to compensate poor consumers for the extra expense of the new bags.

The proposed regulation caused extensive debate, involving environmentalists, consumer organisations, industry and labour unions. Developmental considerations included the position of poor households in rural areas, who more typically use plastic bags available free of charge, and the concerns of workers involved in the manufacturing, packaging and retail industries. Business and unions raised concerns about jobs, income and equipment loss as well as the need to have a holistic approach to waste management rather than targeting a single product. Education, awareness and strong anti-litter penalties were proposed by industry and labour as appropriate responses to the problem of plastic shopping bags waste rather than regulation. A study commissioned by the National Economic Development and Labour Council examined possible impacts of the proposed regulation on investment, employment (including job losses or creation, shifts in skills profiles), distortions in the market (including supply and demand balances and between different products due to the focus on one part of the packaging industry), and industry (e.g. petrochemicals and plastics). The study warned of a possible close-down of the local plastic-bag manufacturing industry, with consequent job losses. It also showed, using recovery economics, that an effective stimulus to local recycling is dependent on addressing constraining factors such as the need to create additional demand in the local market for recycled polymer.

Debates emerged around the need to promote locally made facilities producing two alternatives, namely a "Green Bag" and "Biodegradable Plastic Bag". The case showed the importance of finding reliable life cycle inventory data to compare the environmental

insurance funds, soft loans and other forms of green subsidies. Providing rewards rather than penalties, green subsidies and feed-in tariffs can be important instruments to boost cleaner technologies and green products, as well as waste prevention and recycling schemes. Technology-specific instruments such as green subsidies can help to unlock and guide alternative technology paths. This needs to be combined with appropriate regulation such as carbon taxes. Governments can also develop national financing mechanisms that would particularly provide loans to those SMEs that are willing to improve their resource efficiency but have limited access to financing from commercial banks. Such funding mechanisms could be operated using revenue generated through environmental taxes.

Voluntary action, information and capacity building

In its analysis of environmental policy mixes, the OECD (2007) has argued that in the case of "multi-aspect" environmental problems, policy-makers should supplement instruments that address *total amounts* of pollution with instruments that address *the way* a certain product is used, *when* it is used, *where* it is used, etc. In these cases, regulatory and information instruments are often better suited than for example introducing taxes or credit trading systems. Information instruments can take a variety of forms, including product information, labeling and reporting.

Public institutions can support the validation and harmonisation of eco-labeling schemes, and establish impacts of paper, plastic and cloth carrier bags. A factor in the analysis is different environmental criteria applied, criteria such as primary energy consumption, resource depletion, acidification, nutrient enrichment, eco-toxicity, air and water emissions. Those in favour of paper bags argue that while increased demand for paper bags could lead to more deforestation, paper grocery bags used in many countries today are increasingly made from recycled content.

The environmental levy is one way to make consumers more sensitive to the implications of excessive plastic bag consumption. The question is whether charges for the polluting product should be applied as producer taxes, as behavior-related charges (e.g. returning for recycling deposits) or as simple consumer charges. Experience shows that if, as was the case in Ireland, the levy on plastic bags was set high enough, success was more certain. If however, the levy was set too low, as happened in South Africa, it is not effective in the long term in promoting recycling. To be effective, changes in the price should be large, obvious increases and not small increments. This is the lesson Botswana learned in subsequently following the Irish example, having greater impact with an approach that ensured constant high prices of plastic bags, so that the initial significant decline in consumption continued.

Analyses of the results in South Africa suggest that plastic bag demand is relatively price inelastic, implying that instruments based on price alone would have limited efficacy. While the combination of standards and pricing successfully curbed plastic bag use in the short run, the effectiveness of the legislation may be declining over time. This does not imply that price regulation is necessarily less effective than voluntary action by industry. Rather, the low recovery rate for plastic bags relative to the other packaging sectors can be explained by the differing characteristics of the plastic bags that make them less amenable to recycling. Factors such as their lower value per unit and relative lack of post-recycling applications, implies that they have a low recycling value relative to other waste streams. Regulation therefore has a special role in cases where the material in question has little inherent recycling value, leaving little incentive for industry to take the initiative. Where regulatory initiative is taken, the level of pricing and combination with other factors such as infrastructure and awareness-raising will be decisive.

South African government officials consider the regulation a success and have started implementing similar initiatives to regulate other waste products such as used tyres, oil and glass, confirming a trend towards waste product regulation. The example inspired other countries such as neighbouring Botswana. It also sparked debate about government use of the revenue, and how it could be used to boost the local waste management industry. In addition, it displayed the challenge government faces in introducing a common tax that impacts households of very different income levels. By 2009, in his budget review, the Minister of Finance announced an increase in the levy on plastic bags and the introduction of a levy on incandescent light bulbs targeting local manufacturing and imports. The plastic-bag levy was expected to generate US$2.2 million while the incandescent light bulb levy was expected to generate US$3 million.

Sources: Dikgang and Visser (2010), Fund for Research into Industrial Development, Growth and Equity (2001), Hasson, Leiman and Visser (2007), Nahman (2010), Nhamo (2005) and Yingling Liu (2008)

consumer awareness and education programs to ensure consumers are able to make informed decisions and recognise newly introduced labeling and product information schemes. A recent study for the Ethical Trade Fact-finding Process (ETFP) Group including Consumers International, ISEAL and others, found that the regulation of (environmental) marketing claims is, and self-regulation seems to be becoming, more common (Symbeyond Research Group 2010). [13] In recent years, national eco-labelling schemes have been initiated in Brazil, China, India, South Africa, Indonesia, Thailand and Tunisia.[14] In addition to introducing such schemes in collaboration with the private sector, the public sector can also lead by example and support recognised green labeling schemes and standards through its own sustainable public procurement programmes.

Governments can introduce support programmes with special focus on cleaner production or eco-efficiency,

13. The Eco-label Index database keeps track of 373 eco-labels operating in 25 industry sectors and countries world-wide. (see www.ecolabelindex.com/).

14. By 2000, 43 countries—mostly in Europe and Asia—had household appliance efficiency programs in place, seven times as many as in 1980. Standards "push" the market by requiring manufacturers to meet minimum standards. They are well complemented by eco-labeling programmes, which "pull" the market by providing consumers with information to help them make responsible purchasing decisions, and hence encourage manufacturers to design and market more eco-friendly products (Worldwatch Institute 2004).

targeting specific sizes of companies or specific industries. An example is the provision of management and technology assistance to assist Small and Medium Enterprises (SMEs) in exploiting opportunities for increased resource use efficiency and recycling.[15] Another example would be public-private partnerships for the disassembling and collection of e-waste in socially and environmentally beneficial ways in developing countries that have a comparative advantage in this industry. In addition to creating employment and decent work that meets recognised occupational health and safety standards, a formalised and advanced system of collecting and recycling e-waste can also boost the rate of recovery.

Public institutions can support research and development (R&D), revised educational curricula and training programs to promote cleaner processes and systems, eco-design, products and services. Faced with possible job losses, training needs in the heavy manufacturing industries include training related to change in production processes (energy and resource efficiency, recycling, hazardous waste management), environmental impact assessments, skills upgrading for technicians and retraining into other heavy industries (Strietska-Ilina et al. 2010, Martinez-Fernandez et al. 2010, OECD 2010).

Self-regulation in the form of voluntary initiatives by manufacturing industries includes longstanding initiatives such as Responsible Care by the chemicals industry, with participants from over 50 countries. As of 2004, the International Council of Chemical Associations and its members developed a Global Product Strategy to improve the global chemical industry's product stewardship performance. Since the 1990s, manufacturing industries have been involved in a range of voluntary initiatives started with the aim to fulfill or exceed standards set by legislation. The trigger for these has often been shock events such as industrial accidents during the 1980s. In the last decade, many of these initiatives introduced more systematic stakeholder engagement practices, monitoring and disclosure through reporting requirements. The reporting guidelines of the Global Reporting Initiative have been supplemented by sector specific guidance developed with the mining and metals, automotive manufacturing, telecommunications, apparel and footwear industries. Reporting on strategic management approach by these industries provide an opportunity for investors and other stakeholders to discuss with management what greening the relevant industry entails.

From an overview with 22 industry groups of progress made since the 1992 Rio Summit with sustainable business practices, UNEP (2002) among others recommended that voluntary initiatives be made more effective and credible as a complement to government measures. In an update of this review five years later, UNEP (2006) received report cards from 30 industry groups including the manufacturing sectors covered in this chapter. Industry groups reported voluntary initiatives for promoting awareness and integration of sustainability concepts into their daily operations as well as initiatives related sustainability reporting. Many industries reported the development of sector-specific voluntary standards. Some of these were developed in consultation with regulatory authorities (e.g. the automotive sector's fuel-efficiency standards in Europe). Few referred more specifically to certification and labelling initiatives, as was done by for example the pulp and paper industry.

The reporting process facilitated by UNEP (2006) showed growing interest in measurement of progress in greening industry. Use of and reporting against agreed indicators at industry sector level can help to fill the gap between national, macro level and company, micro level indicators. The Iron and Steel Institute for example reported agreement by its Board on the use of 11 indicators, which resulted in a collective report for which 44 member companies provided data.[16] The International Aluminium Institute reported agreement by its members to twelve sustainability objectives supported by 22 indicators. It developed a material resource mass-flow computer model to identify future recycling flows. The model projected that global recycled metal supply from post-consumer scrap will double by 2020 from a 2004 level of 6.7 million tonnes. It undertook to report annually on its global recycling performance.

15. UNEP and UNIDO have been supporting such approaches through a growing network of National Cleaner Production Centres in developing countries (see www.unep.fr/scp/cp/network/).

16. The four economic indicators were: investment in new processes and products, operating margin, return on capital employed, and value-added. The five environmental indicators were: greenhouse gas emissions, material efficiency, energy intensity, steel recycling, and environmental management systems. The two social indicators were: employee training and lost time injury frequency rates (UNEP 2006).

7 Conclusions

This chapter has provided an overview of a number of greening opportunities in the manufacturing industries, focusing in particular on sub-sectors that are main contributors to GHG emissions globally and that have high impact by virtue of their broader contribution to global resource use, associated environmental impacts, GDP and employment. It has noted the growing importance of manufacturing to developing countries, responsible for 22 per cent of global GDP by 2009.

The analysis has shown challenges manufacturing faces, highlighting the costs and risks of inaction and an illustrative BAU scenario to 2050. In major economies, the external costs of air pollution – mainly in the form of health costs – could be well over 3 per cent of global GDP. The possible future scarcity of some natural resources, for example growing dependency on water, poses risks associated with operations, markets, finance, regulations and reputation. Reserves of easily accessible oil are being depleted. While global demand for metals such as copper and aluminium is increasing, high quality metal ores are gradually being depleted. Increasing resource scarcities put upward pressure on commodity prices and on the manufactured products for which they are used as inputs.

While progress is being made in responsible chemicals management, concerns persist about the lack of thorough evaluation of the effects on human health and environment of thousands of chemicals on the market. The case of three toxic metals – mercury, lead, and cadmium – show the challenges that globalisation and trade brings; the metal often sourced in one region of the world, refined in a second, incorporated into products in a third, and disposed of in yet another region. These realities challenge large corporations and their supply chains to improve traceability and safe management practices globally. Recent industrial accidents provide stern reminders of the costs of unsafe practices in the management of hazardous substances.

Real opportunities for manufacturing lie in taking a life cycle approach to its logical consequences and pursing supply and demand side strategies to close the resource use cycle in manufacturing. Such strategies could enable even rapidly industrialising economies to decouple environmental damage from economic growth and improve their longer term competitiveness. At the industry level, the greening transformation involves a value chain that starts with the re-design of products, production systems and business models, and leads to extended producer responsibility in the form of take-back or reversed supplies, remanufacturing and recycling on a scale not seen before. The case of metal stocks in our economies is illustrative. While only a few metals currently have an end-of-life recycling rate of above 50 per cent, there exist many opportunities to improve recycling rates and increase secondary production which requires potentially only a fifth of the energy and causes up to 80 per cent fewer GHG emissions than primary production.

Investment strategies for greening manufacturing highlighted investment in cleaner technologies and innovation, associated benefits in efficient use of energy and water, investment in a transition towards green jobs and likely prospects for resource efficient growth in developing markets. Following years of automation and related cuts in manufacturing jobs, the "greening" of manufacturing will not generate jobs in all sectors. However, recycling and remanufacturing has considerable potential to create jobs. There will also be more skilled jobs in energy-service companies, in repair and maintenance, and in recycling scarce materials. Government training programs to upgrade skills will be needed in virtually all countries, but the kinds of skills required will vary according to the level of development of the local industry.

Results of the simulations indicate that investing in greening the manufacturing industries will help reduce energy consumption and emissions, reduce the upward pressure on prices of fossil fuels and – through avoided energy costs – help boost productivity and profit whilst stimulating GDP and overall employment. From the sectors covered in this chapter, the chemical and plastics industry shows the greatest potential for energy savings. To track progress in how a green investment scenario evolves, governments need to begin to collect improved data on industrial resource efficiency.

Overall, there is abundant evidence that the global economy still has untapped opportunities to produce wealth using less material and energy resources. It is important to understand though that increasing resource efficiency is consistent with almost any definition of green, whereas cutting carbon or other GHG emissions *per se* may not be consistent with increased efficiency. An example of this is CCS technology, which is very energy intensive and resource *in*efficient. In sharp contrast, the wider implementation of comprehensive efficiency incentives, recycling, and combined heat and power (CHP), together with closed-cycle manufacturing (repair, renovation, remanufacturing and recycling), will correspondingly increase resource efficiency. In many cases this could reduce extraction and processing costs, thereby supporting economic growth.

Discussion on the enabling environment highlight two recommended policy priorities, namely (i) closed-cycle manufacturing with supportive infrastructure, and (ii) regulatory reform to enable factor efficiency improvements in energy use through greater use of cleaner technologies such as combined heat and power (CHP). Governments should seek ways to encourage closed-cycle manufacturing, for example, by encouraging large multinational systems integrators who manufacture aircraft, automobiles, home appliances, electronic goods, etc. to be responsible for integrated materials management throughout the entire supply and demand chain from the point of extraction to final disposal. The main objective must be to make manufactured goods last longer, by means of greater emphasis on re-design, repair, reconditioning, re-manufacturing and recycling. Extended producer responsibility (ERP) laws, refundable deposit schemes, and improving the functioning of markets for secondary raw materials are the most likely tools for getting started.

Each country will need to consider its appropriate policy mix of regulatory instruments and approaches to make the transition happen, mindful that basic physical processes and damaging impacts associated with pollution and unsustainable resource use are universal. As major point sources of pollution, the manufacturing industries have traditionally been easy targets of command-and-control regulations. In some cases these need reform, in others new ones are required to scale up transformation. Command-and-control regulations need however to be better combined with market-based approaches, allowing appropriately structured markets to reflect the real price of energy and other resources and allowing manufacturing industries to innovate and compete on a fair basis. Recent history shows that the introduction of taxes can be a strong driver for technology innovation (cf petrol taxes and vehicle engine technology). Use of economic instruments can also reduce monitoring costs for regulators, but requires a willingness to undertake thorough economic analysis on their likely costs, benefits and effectiveness in order to design them correctly.

The concentration of certain heavy industries in some countries, as well as the dominance of their markets by a core group of corporations may point to opportunities for advancing climate mitigation strategies with an industry-sector approach, even if only on a national basis. This may be a way of addressing competition concerns and avoiding capital lock-in by industrialising countries in outdated technologies. At the same time, crediting and trading schemes are likely to offer greater economic efficiencies if introduced across industries. This can also be explored throughout global supply chains by using CDM-type projects to share cleaner technology applications among developed and developing markets.

Governments will also need to consider ways of supporting the greening of manufacturing through *institutional support and soft technology approaches,* for example, education and training in areas such as cleaner production and considering smaller, supplier enterprises in particular. Institutional support can vary from the financial, ensuring the provision of green subsidies and loans, to the provision of infrastructure, ensuring appropriate systems for deposit refunding, waste recovery, recycling and distribution. Scaled-up investment in establishing eco-industrial parks can be a key building block in this, an area open for public-private partnership. Voluntary initiatives by manufacturing industries over the last ten years have shown growing willingness to measure and communicate relevant performance and discuss with investors and other stakeholders what indicators to use in the process. Greening national economies and markets require reliable methodologies underlying these and similar efforts to communicate performance via green product labels and certification schemes.

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