Industrial energy and material efficiency: What role for policies?

Mohan Peck and Ralph Chipman*

This chapter is divided into two parts which explore the role for policies in promoting industrial energy and material efficiency. Economic and environmental pressures for energy and material efficiency have been increasing in the past few decades, resulting in noticeable advances in process and product design and in making waste more recyclable and reusable.

According to the World Energy Council, energy efficiency has a broader meaning than mere technological efficiency of equipment; it encompasses all changes that result in decreasing the amount of energy used to produce one unit of economic output (e.g. the energy used per unit of GDP) or to achieve a given level of comfort. Energy efficiency is associated with economic efficiency and includes technological, organizational and behavioural changes.[1] The importance of energy intensity of national economies as an indicator of sustainable development was agreed in Agenda 21, which states that "reducing the amount of energy and materials used per unit in the production of goods and services can contribute both to the alleviation of environmental stress and to greater economic and industrial productivity and competitiveness."

Material efficiency in industrial production, on the other hand, can be defined as the amount of a particular material needed to produce a particular product. Material efficiency can be improved either by reducing the amount of the material contained in the final product ("lightweighting"), or by reducing the amount of material that enters the production process but ends up in the waste stream. In a slightly broader sense, taking into account the industrial production-consumption cycle, material efficiency can refer to the amount of virgin natural resources required for producing a given amount of product, with recycling of post-consumption waste material back into production contributing to material efficiency. Three components of material efficiency can therefore be identified: lightweighting in the production process; waste reduction in the production process; and recycling of material in the production-consumption cycle.

Public policies have generally focused on the third of these, recycling, with improvements in material efficiency within industrial production,

* Policy Integration and Analysis Branch, Division for Sustainable Development, UN-DESA, United Nations, New York. The views expressed in this document are those of the authors and do not necessarily coincide with those of the organization to which they are affiliated.

either through lightweighting or waste reduction, generally left to industry. The discussion here will therefore focus on policies promoting recycling.

A. Energy efficiency in industry

Energy efficiency is rising toward the top of many national agendas for a number of compelling reasons that are economic, environmental and intergovernmental in nature. As many industries are energy-intensive, this is resulting in new impetus to industrial energy efficiency policies. The economic reasons are quite clear. Most important has been the rise in energy prices from 2005-2006 and their likely continuation at a high level. Increasing concerns over energy security (reliability of supply) are a second factor. Energy supply in many countries increasingly depends on imported oil and gas, and supply is being constrained by geopolitical events while global economic growth is resulting in greater energy demand. Additionally, in many developing countries energy efficiency is also a way to alleviate the investment costs for expanding energy supply infrastructure in the face of tight fiscal constraints.

Environmental pressures are also exerting influence. There is now the need to reduce greenhouse gas emissions to meet commitments under global environment agreements, particularly for Annex 1 signatories to the Kyoto Protocol. In the European Union and in other countries, cap and trade carbon dioxide (CO_2) emission trading schemes are now in place, compelling them to reduce greenhouse gas (GHG) emissions, and the focus is often on energy-intensive industries. Moreover, environmental directives in major markets are influencing global industrial supply chains. For example, the European Union's Directive for Energy-using Products (EuP) encompasses the entire life cycle of a product: design, manufacturing, use and disposal, and sets legal requirements for energy use of manufactured products.

Finally, energy efficiency has recently been high on the intergovernmental agenda, where it was a main topic of discussion in the G8 meetings at both Gleneagles and St. Petersburg. Energy efficiency and industrial development are also currently on the agenda of the 14th and 15th sessions of the United Nations Commission on Sustainable Development, which will result in recommendations for international action. Industrial energy efficiency also figures prominently in the "Marrakech Process" on sustainable consumption and production.

Industry is the largest energy end-use sector in the world today and consumed 30 per cent of delivered energy in OECD countries in 2003.[2] Moreover, energy use in the industrial sector is forecast to grow an average of 2.4 per cent per year through 2030 – 3.2 per cent in developing countries and 1.2 per cent in developed countries.[3]

A wide variety of energy efficiency policies, programmes, products, services and delivery mechanisms have been implemented by countries in efforts to improve energy efficiency in industry. Results in developed countries due to such efforts have been significant. For example, while the manufacturing output of the OECD countries has doubled since the 1970s, the amount of energy used in manufacturing has not changed (World Energy Council, 2004). While it is true that most of those gains were achieved between 1973 and 1986 as a response to high oil prices, many opportunities for significant energy savings continue to exist.

Energy efficiency efforts have been shown to be more likely to succeed if a supportive framework of policies and regulatory environment exists. This framework may include: overall energy policy; power sector reform; energy efficiency policies, laws and targets; the establishment of energy efficiency agencies within governments; utility demand-side management programs; negotiated agreements with industry; support and promotion of energy audits; and energy efficiency standards, codes, testing, certification and labelling.

1. Trends in industrial energy intensity

Energy efficiency is a main determining factor of industrial energy intensity, but another important factor is structural change in the economy (such as growth of the service sector). At the world level, there has been a continuous decline in primary energy intensity. Global energy intensity is expected to decline at a rate of between 1.5 - 1.9 per cent per annum between 2003 and 2030, depending on economic growth.[4] As shown in Figure 1, there is considerable regional variation in industrial energy intensity. The clear trend has been a continuous decline in industrial energy intensity with significant strides made in China and North America. The exceptions are the Middle East and Africa where energy intensities are still climbing.

Figure 2 highlights energy use and trends in energy-intensive industries in the EU-15. Primary metals, non-metallic minerals and chemicals, as the largest energy-consuming sectors, have over the past decade been the focus of negotiated agreements to achieve energy efficiency and, as a result, significant progress has been made in reducing their energy intensities. Other sectors such as paper, food and textiles show minor increases in the amount of energy required for a unit of output.

2. Market-based measures for energy efficiency

During the past decade, liberalization of energy markets, as a process, was initiated in the Australia, Canada, United Kingdom and United States. The EU established rules to liberalize its electricity market, which became operational in 1999, and liberalization of the natural gas market is now being phased-in over time. Liberalization of the energy markets in developing countries and economies in transition has taken place in a number of countries under World Bank structural adjustment programmes, one of the main objectives being to attract private capital to expand and improve the sector.[5]

The change from vertically integrated, monopolistic sectors to competitive markets has also changed the way governments intervene in the energy sector. Instead of regulating monopolies, governments are now in the process of introducing a range of market-based measures. A number of these measures promote energy efficiency either directly or indirectly (for example through reduction of greenhouse gases).

Tax and fiscal policies encourage investment in energy efficient equipment by increasing the cost of energy or reducing the cost of investments. Main targets for these policies are energy-intensive industries, energy service companies and equipment vendors. Such incentive programmes typically have short-term objectives of increasing energy efficiency by 10 per cent and long-term objectives as high as 25 per cent as compared to a baseline year. For example, fiscal incentives in Japan encourage the acquisition of energy efficient equipment. The Energy Conservation Law enacted in 1993 introduced several special tax measures related to energy efficient equipment. These included: a corporate tax rebate equivalent to 7 per cent of the purchase price; and accelerated tax depreciation for new equipment yielding at least a 5 per cent energy savings. As a result of the incentives, investment in energy efficient products increased by US$4 billion per year for several years during the 1990s (Price et al., 2005).

Case Study on Economic Incentives: China

Price reform in China has increased economic incentives for conservation. In 1994, except for coal used for power generation, all price subsidies for coal were withdrawn. In 1998, for the first time, domestic crude oil prices were allowed to float with international oil prices. Controls on the prices of oil products were removed in 2000. Prices rose substantially once these subsidies were lifted and, as economists would expect, energy-intensive industries reduced consumption of these resources. As an example, energy prices in the iron and steel industry increased by a factor of three between 1986 and 1995. Forced to pay the full cost of their energy inputs, firms responded by finding ways to conserve energy and reduce energy expenditures. Over this ten-year period, the iron and steel industry realized energy savings of 15 Mtoe and avoided an estimated 3.87 billion Yuan in energy expenditures (World Energy Council, 2004).

2.1 Taxes and charges

Energy or energy-related CO_2 taxes have the advantages that they reduce demand for the taxed product, they increase public revenues and they reduce pollution and its related impacts. These taxes have the disadvantage that they may negatively affect the competitiveness of an industry. Such taxes were first introduced in the 1990s in Europe and are now in practice throughout the EU.

UK Climate Change Levy

Established in 2001 with an environmental goal of reducing CO_2 emissions by 2 Mt per year, this is a levy on the sales of electricity, coal, natural gas, and liquefied petroleum gas to the business and public sectors. The levy adds 15 per cent to typical energy bills for the business and public sectors, but companies that meet negotiated energy efficiency improvement targets receive an 80 per cent levy discount. The revenues collected contribute in part to government support for energy efficiency measures and energy-saving technologies. The levy is not set in relation to carbon content of various fuels (Oikonomou and Patel, 2004).

Pollution levies are imposed by a wide number of countries for violations of pollution emission standards that are often associated with energy use. Such levies are usually imposed on energy-intensive industries and levels of penalties for offences have been rising over time. Efforts are often made to balance the social and economic benefits of the services violators produce with the environmental harm. Countries have developed systems with both civil and criminal penalties. Civil penalties have the advantage that it is only necessary to show that a violation of regulations has occurred, and no lengthy judicial hearings are required; consequently, the majority of penalties imposed come as a result of civil actions. Penalties for pollution levies can range from warning notices or small fines issued in field actions, to substantial administrative penalties, to legal settlements requiring payments of large sums and requirements to install pollution mitigation equipment (see table 1). For example, several manufacturers of diesel engines were jointly penalized over US$1 billion for installing special computer chips that allowed their engines to pass laboratory inspections when in conditions of actual operation they exceeded the emissions standards.[6]

Restructuring of public electric utilities in the 1990s introduced competition but also reduced incentives for demand-side management programmes. To regain the benefits of DSM programmes, *public benefits charges* were introduced whereby a fee is imposed on electricity distributed to all users. Most experience has been in the United States where 25 states currently have energy efficiency programmes funded by public benefits charges. But other countries, such as the UK, Australia, Norway, and Sweden, found the same underinvestment in energy efficiency after deregulation and developed similar programs funded through general revenues or through charges on energy consumption. In the US, as of 2005 these funds have financed over US$900 million of spending on energy efficiency programmes leading to average annual reductions in power demand of 0.4 per cent and a total reduction in demand of over 1,000 MegaWatts (MW) (Price et al., 2005)

Public Benefits Charge in New York

New York's Energy and Research Development Authority (NYSERDA) provides a number of energy efficiency related services to the industrial sector using funding from a public benefits charge. Services include 50 per cent cost-shared on-site engineering studies, an ESCO-administered industrial performance programme, and a loan fund that provides interest rate reductions on energy efficiency investment projects.

2.2 Financial incentives

A range of incentive measures may aim at reducing costs associated with increasing energy efficiency, including subsidies or grants for energy efficiency investments, tax relief for purchase of energy efficient equipment or for participation in negotiated agreements, subsidies for energy audits, and loans or guarantee funds for energy efficiency projects.

Subsidies or grants for the purchase of energy efficient equipment are the most widespread fiscal incentive in use today. Subsidies and grants are particularly useful to encourage energy efficiency investments in developing country environments where perceived risks may be higher and where competition with infrastructure projects may put energy efficiency projects at a disadvantage. They also effectively stimulate energy efficiency measures in countries where energy prices do not reflect the real costs of energy and are too low to allow financial benefits to accrue to energy projects through energy savings. To make a subsidy programme more effective, care should be given to avoid free riders (those companies that would have upgraded their equipment even without a subsidy) and to reduce transaction costs.

One market-based approach to energy efficiency is the development of an *energy service company* (ESCO) industry. An ESCO is a company that is engaged in developing, implementing and financing performance-based projects that seek to improve energy efficiency or reduce electricity loads of facilities owned or operated by customers. ESCOs are promoting energy efficiency around the world but particularly in countries experiencing increased competition and privatization in the electric utility business, as well as in other sectors undergoing liberalization, e.g., heat production in Central and Eastern Europe. Since ESCO remuneration is often tied to the level of energy savings, it makes good business sense for them to target energy intensive industries.

Energy audits of industrial enterprises are key to assessing the potential for energy savings and for identifying energy efficiency measures that could be employed. Energy audits of industrial enterprises are often subsidized or provided free of charge to encourage participation and to facilitate the adoption of modern energy efficient technologies. For example, in France ADEME provides a subsidy of 50 per cent for audits conducted on Industrial sites. About 75 per cent of the companies that received the subsidy stated that they made investments immediately after the audit. The subsidy programme cost the public about € 76 per toe saved and yielded investments with an average cost of € 570 per toe savings per annum, which yields a savings of approximately € 1500 for every toe saved at 2006 oil prices. In some countries, regular audits are mandatory for large energy consumers. In Portugal, Thailand and Tunisia, audits are mandatory for buildings and large factories using over 1000 toe per year. According to the World Energy Council, subsidies generally cover 40-100 per cent of the cost of an energy audit. The Korea Energy Management Corporation performs approximately 2000 energy audits every five years and roughly 80 per cent of the audits are performed for free. A sample of eight audits in the industrial sector required an investment of US$48.65 million and yielded energy savings of 198,604 toe annually. This amounted to annual cost savings of US$37.33 million with an average pay back period of 1.3 years (World Energy Council, 2004).

In many countries, financing of energy efficiency investments is made possible via a combination of soft *public loans and innovative private financing*, aimed at increasing the involvement of private capital. Such innovative financing instruments include ESCO funding, guarantee funds, revolving funds and venture capital. ESCOs sometimes use a shared savings approach in which the ESCO guarantees the energy savings of the project and secures the needed upfront financing. Guarantee funds provide a repayment guarantee to banks granting loans for energy efficiency projects and thus cover the associated credit risk. This is particularly useful in developing countries where financial institutions have little experience in making loans to often asset-free energy efficiency projects.

France, Hungary, Brazil and China have established *loan guarantee* funds for energy efficiency projects. The guarantee fund set up in France is directed to energy efficiency projects of small and medium-size companies (SMEs) which typically have trouble financing energy efficiency due to the small size of their projects. The national guarantee fund covers 40 per cent of the risk, the French Agency for Environment and Energy Management (ADEME) covers an additional 30 per cent of the risk, and a national bank supporting SME growth provides soft lending terms. This fund guarantees up to € 242 million for loans to the private sector. Its goal is to provide SMEs with the option to obtain loans for energy efficiency and renewable energy investments.[7]

Taxes and fiscal incentives promoting industrial energy efficiency in selected countries are summarized in table 2.

One of the most significant co-benefits of energy efficiency is its contribution to GHG emission mitigation. *Carbon dioxide emission trading schemes* are now in place both within the EU and among signatories of the Kyoto Protocol. While designed with environmental goals, these market mechanisms also provide incentives for energy efficiency. The EU Emission Trading Scheme (EU ETS) will cover about one-half of the EU-25's total CO_2 emissions by 2010, including all the energy intensive industries. While significant energy efficiency gains are expected as a result of the EU ETS, greater gains could be realized if there was tighter and more consistent target setting. International commitment to post-2012 Kyoto targets is also needed. The Clean Development Mechanism within the Kyoto Protocol supports, among other things, energy efficiency projects that can certify emission reductions with an approved methodology. The first such projects are now being piloted.

White certificate programmes for energy efficiency are being implemented in Italy, the UK, France, Belgium and New South Wales, Australia. In these programmes electricity and gas utilities are required to promote energy efficiency among end-users and to show that they have saved an amount of energy that is a percentage of the energy they distribute. That amount of energy saved is certified through "white certificates". These certificates can then be traded, with those parties that do not meet their energy saving targets having to purchase certificates in the market (Farinelli et al., 2005). The white certificate program in Italy was launched in January 2005. Figure 3 shows the energy savings targets and projected evolution of energy savings over the first 5-year compliance period in Italy with respect to the electricity sector due to white certificates. During this phase of the programme, 3 million tons of oil equivalent (Mtoe) of cumulative primary energy savings are projected to be realised, of which 1.6 Mtoe by electricity distributors and 1.3 Mtoe by natural gas distributors (Bertoldi and Rezessy, 2006).

3. Policies for industrial energy efficiency

Figure 4 depicts the various energy efficiency policies employed by over sixty countries[8] and identifies the percentage of countries that use a particular policy. The survey was conducted in 2004 by the World Energy Council and the French Agency for Environment and Energy Management. The chart does not indicate the effectiveness of those policies, their impact, or whether the targets or stipulations of those policies were ambitious or lax.

Negotiated agreements between government and industry to improve energy efficiency are playing a significant role in both developed and developing countries (see table 3). While most programmes are voluntary, they generally provide either incentives and/or penalties to encourage participation by companies. Typically, companies or industry associations set targets for reducing energy use or greenhouse gas emissions in exchange for government support, such as financial incentives, publicity, or relief from other environmental or tax obligations. Negotiated agreements may be categorized in three ways: 1) those that are entirely voluntary; 2) those that have implied threats of regulation or taxation; and 3) those with a mix of incentives and penalties for non-compliance. As voluntary programmes have few incentives and lack penalties, they tend to have less participation by industry and results are usually small improvements on business-as-usual. Programmes with implied future threats of regulation or taxation promise easy environmental permitting, relief from regulations, and avoidance of energy or GHG emissions taxes in return for participation. As a result these negotiated agreements have been more successful; for example, the Netherlands achieved an industrial energy efficiency improvement of 22.3 per cent between 1989 and 2000. Programmes with a mix of incentives along with penalties for non-compliance achieved both wide participation and strong results. Participation by industrial enterprises in these agreements is generally high, representing about 90 per cent of industrial GHG emissions in Canada, Denmark, New Zealand, Switzerland and UK.[9]

Negotiated Agreements in The Netherlands

Under a new Long Term Agreement entitled "The Covenant on Benchmarking Energy Efficiency", industrial enterprises commit to achieving "best of class" energy efficiency amongst comparable companies by 2012. This level is determined as being 90 per cent as efficient as the best performing enterprise. Implementation begins in 2006 and if a company is not in the best of class by 2008 it has the option to make additional energy efficiency improvements or make trade-offs using the Kyoto mechanisms (Rezessy, Bertoldi and Persson, 2005).

Higher levels of end-use energy efficiency can allow deferral of a part of the investment needed to meet growing energy demand. While electric utilities in developed countries have been implementing *demand-side management (DSM) programmes* aggressively during the past 25 years, the electricity sectors in developing countries have had little exposure to the DSM process. Until the early 1990s, subsidized energy prices, non-competitive end-use markets, lack of sufficient DSM knowledge and expertise, and the absence of adequate regulatory and institutional support were the primary factors limiting DSM activities in developing countries. However, as increasing numbers of these countries adopt pricing schemes that reflect actual costs in their electricity sectors, the incentives are likely to increase for realizing energy and capacity savings through DSM.

Case Study on Demand Side Management: Thailand

In Thailand, the national utility's DSM program, supported by a GEF project, has exceeded targets, with a 566-MW peak load reduction and 3,140 GWh annual energy savings. The utility created a dedicated DSM office that now has a staff of 375 people. The DSM office is implementing 13 different energy efficiency programs for refrigerators, air conditioners, green buildings, industrial cost reduction, industrial ESCO development, motors, compact fluorescent lamps, street lighting, thermal storage, stand-by generation, interruptible loads, time-of-use tariffs, and public awareness campaigns. The private sector has been engaged, through workshops with distributors and retailers to encourage sale of high-efficiency refrigerators and air conditioners, and through negotiations with manufacturers to produce high-efficiency equipment (Singh and Mulholland, 2000).

Energy performance standards and labels: Electricity consumption is rising worldwide every year as people gain access to electricity and become increasingly dependent on electrical equipment. In industry, electricity motors power pumps, compressors, fans and a wide variety of machinery. One of the most cost-effective and proven methods for increasing energy efficiency at industrial enterprises is to establish energy efficiency standards for industrial motors. Currently, minimum energy performance standards for motors have been adopted in 30 countries. According to a study by the European Copper Institute, European industry could save over 200 billion kilowatt hours (kWh) of electricity per year by using more energy-efficient electrical motor systems. Research by the EU's motor challenge programme found that industry across the EU-25 could save € 10 billion per year on its electricity bills plus a similar amount from reduced maintenance. Carbon dioxide emissions would be reduced by 100 million tonnes per year, equivalent to one quarter of the EU-15's Kyoto commitment.[10] Labelling of efficient motors has been shown to boost their sales. At present 26 countries use a labelling scheme to help industrial purchasers identify energy efficient motors. Examples of labels for energy efficient motors from four countries are shown in figure 5.

Benchmarking provides a means to compare the energy use within one company or plant to that of other similar facilities producing similar products. Benchmarking can be used to compare plants, processes or systems. For example, systems such as compressed air systems can be benchmarked to evaluate energy efficiency, such as Germany's REN Strom programme. Benchmarks are typically employed as part of negotiated agreements and are supplied to all participating companies. Those companies participating in the negotiated agreement then agree to achieve the efficiency level of the top 10 per cent of plants.

Benchmarking Tool

The Lawrence Berkeley National Laboratory in the US has produced a Benchmarking and Energy-Saving Tool (BEST) that compares each process used at a plant with world best practice. The software allows industrial users to select from a broad array of energy-efficiency technologies and measures that could be implemented. The software tool is process-related and includes motor systems, boilers, steam distribution and cogeneration, among other things. Apart from characterizing the energy savings, the software also captures non-energy benefits such as reduced emissions, reduced water use, increased productivity, etc.[11]

Monitoring and targeting (M&T) is a tool that often provides useful information when implementing other energy efficiency measures, thus making them more effective. It also ensures accountability by providing feedback on performance improvement measures that have been implemented, assessing energy savings achieved. It can also be an effective tool to change corporate thinking about energy saving at all levels from corporate management to operational staff and, as such, can lock in efficiency gains through a strategy that influences corporate culture and promotes behaviour modification. M&T has a long history in the UK, which launched a national programme in 1980. Over 50 industry sector studies have demonstrated the benefits of monitoring and targeting. These benefits include:

- Energy savings of 5 to 15 per cent with similar reductions in emissions of CO_2 and other pollutants;
- Coordination of energy management policy through targeting of initiatives that achieve the maximum benefit;
- Assisting with financing for energy efficiency projects, through determination of baseline energy use levels for energy efficiency project proposals, and verification of savings (critical for performance contracting by ESCOs);
- Improved product and service costing, through better understanding of the energy content of products and services;
- Improved budgeting, by providing improved data for the accurate projection of future energy use.

Apart from the UK, the World Bank and others have supported activities that apply the M&T approach in improving energy efficiency in the industrial sector in Brazil, Peru, Colombia, and Slovakia. A recent European Commission Green Paper on energy has set a target of reducing EU energy consumption by 20 per cent compared to projections for 2020.

M&T Case Study: Unilever Canada

In the late 1990s, Unilever Canada analyzed several alternatives in a bid to reduce the utility bills at one of its facilities. A study concluded that an in-house monitoring and targeting (M&T) program could bring a potential saving of US$700,000 per annum - US$260,000 from technical projects and US$440,000 from operational efficiency improvements. The M&T program was implemented in 2001 and the actual results exceeded initial projections with a year-end total energy savings of US$1million.[12]

Websites for industrial energy efficiency are proliferating rapidly and contain tools, guidebooks, information and links on energy efficiency programmes, policies, technologies, financing and technical assistance. The EU's CORDIS website provides access to information on available support programmes, databases and reports, while its ManagEnergy website has similar tools and includes links to over 400 energy agencies, events and partner searching capabilities. Sweden's STEM website includes a calendar of energy efficiency events online (Galitsky, Price and Worrell, 2004).

An overview of industrial sector energy efficiency program products and services of industrialized countries is presented in table 4.

Market transformation policies and programmes for energy efficiency have been widely employed by industrialized countries and in recent years are being increasingly adopted by developing countries and economies in transition. Market transformation programmes for energy efficiency a) intervene strategically in the market, b) create long-lasting changes in the structure or functioning of the market, and c) lead to widespread adoption of energy efficient products, services and practices. Market transformation efforts that have been employed to "push" technology innovation include a range of measures such as promoting technology transfer for domestic manufacturing, adopting minimum energy performance standards for energy consuming equipment, developing voluntary agreements with manufacturers, developing new lines of distribution through electric utilities or retailers, and arranging soft financing terms for manufacturers. Other efforts have been designed to "pull" the market; these have included helping consumers to make informed purchase decisions through media campaigns or point-of-purchase aids such as energy efficiency labelling, lowering prices via subsidy or rebate, encouraging bulk purchase/procurement, establishing buy-back or recycling programmes, and providing financing of purchases through banks or utility bills. To date, a host of market transformation initiatives have been implemented in a number of countries that targeted residential appliances (e.g., lighting, refrigerators, and air conditioners), commercial buildings, industrial sectors, and government facilities.

Market Transformation of China's Refrigerator Industry

A project funded by UNDP/GEF and implemented by China's Environmental Protection Administration in cooperation with UN/DESA has succeeded in transforming the Chinese refrigerator market. China has the world's largest refrigerator industry but, prior to the project, the average refrigerator consumed up to 2.5 kWh a day (compared to 1.5 kWh a day in Europe).

Project partners worked with 16 refrigerator manufacturers to help build capacity for research and design of energy efficient refrigerators. New government regulations were also researched and implemented that changed the rules of the market and forced manufacturers to make technology upgrades. In addition, innovative incentive programs were introduced for manufacturers and retailers in order to spur competition.

The project obtained commitments from each participating refrigerator manufacturer to design one new top-rated equivalent refrigerator (that consumes less than 55 per cent of the average current energy use); improve the efficiency of the average refrigerator by at least 10 per cent; and invest at least 10 per cent of their advertising budgets to promote energy efficient refrigerators.

A US$3 million national consumer education campaign raised awareness of the benefits of energy efficient refrigerators in terms of lower operating costs and mitigation of environmental impacts. The advertising campaign directed to television, radio and print media was highly successful and won two national awards for excellence in advertising.

As a result of the above measures which all came together in 2005, the overall project goal of 20 million refrigerators sold yielding lifetime product emission reductions of 100 million tons of CO2 and energy savings of 66 billion kWh was not only met but doubled (UN-DESA, forthcoming).

4. Policies for supply-side efficiency in energy industries

Both developed and developing countries have pursued regulatory reform and liberalization of the electric power industry. They have done so in the expectation that such reform and restructuring could yield important benefits, namely improving economic efficiency, lowering costs and consumer prices and stimulating economic growth and competitiveness. These expectations have to some extent been realized. For example, in some formerly public-owned companies, labour productivity has improved by up to 60 per cent and generating costs in some cases have declined by 40 per cent. In other countries, availability of generating plants has improved significantly (from 60 per cent to 87 per cent), customer outages have been reduced, distribution company productivity has improved, and prices have been reduced by 13-20 per cent in electricity markets (OECD, 2000). Wider economic benefits are also possible, given that electricity is an input to almost all productive activities. However, the impact of market liberalization on long-term investments in generating capacity is not yet fully clear, particularly in developing countries.

The improvement in efficiency after privatization of four South American distribution companies is summarized in Table 5. These improvements were measured in terms of the change in performance between the date of privatization and a point in time approximately five years later (ten years in the case of Chile). The four companies showed substantial improvements in performance according to all the indicators. These improvements show the benefit of having private management focus on commercial performance, which has been a major weakness of state-owned utilities.

Case Study on Electricity Market Reform: Colombia

Colombia undertook a "middle of the road" approach to electricity sector reform beginning in 1994 which continues today. In 1994, 100 per cent of the electricity sector was publicly owned but it suffered from inadequate capitalization and inability to attract investment. In 2005, 55 per cent of the generation capacity and 50 per cent of the distribution capacity is in private hands. The sector is efficient and transparent, system availability and reliability have markedly improved, and electricity losses have been reduced. There still remains a challenge of rural electrification (30 per cent of the population still has no access). The regulatory authority has significantly changed the "rules of the game" but it has only limited independence. Privatization has resulted in the participation of 37 private companies valued at US$2 billion. Tariffs are competitively priced but competition is affected by cross-subsidies. Since 2003, operations have yielded a financial surplus (Herz, 2005).

Another area of significant potential energy savings in the electricity sector lies in the reduction of transmission and distribution losses, which in many developing countries are high due to technical and non-technical losses. For example, at the end of 2005, India had 122,275 MW of installed capacity but only 66 per cent of that capacity was available due to inefficient transmission and distribution.[13] The result was frequent power shortages and load shedding. Although the generating capacity is set to increase, the transmission and distribution sector remains congested and inadequate with losses amounting to approximately 25 per cent, compared to less than 15 per cent which is an acceptable rate in most developing countries[14] and approximately 5 per cent in developed countries. Countries facing a similar challenge to that posed in India might consider a number of possible solutions, including:

- Attracting further investment for transmission infrastructure through easing licensing requirements for entering the transmission and distribution business.[15]
- Strengthening metering, billing and enforcement efforts as a means of reducing the high level of electricity theft.
- Introducing availability based tariffs to improve grid discipline and reduce transmission losses.
- Promoting distributed generation to both industrial parks and remote locations to avoid transmission losses.
- Raising consumer awareness regarding practical energy conservation measures and the benefits of choosing energy efficient appliances.
- Increasing the percentage of renewable sources in the energy mix to provide more options for decentralized generation and to reduce emissions.[16]

Combined heat and power, or cogeneration, represents another clean energy path for industry. Worldwide, 65 per cent of fuel energy consumed in electricity generation is lost as waste heat. Building or adapting power plants for cogeneration of electricity and heat can reduce those losses to 20-30 per cent. After generating electricity, the waste heat can be recovered and then used for, among other things, process steam, space heating, air conditioning, water cooling and product drying. Alternatively, clustering of industrial enterprises in industrial parks facilitates opportunities for cogeneration of electricity using waste heat from industrial processes. Auto-production of electricity by industry has the co-benefit of reducing peak load on the electricity network. Installed cogeneration capacity in 2004 amounted to 6,926 GW and has been growing at between 2.5 to 3.0 per cent annually.[17] The share of cogeneration in global electricity generation is just over 7 per cent, despite its enormous potential. Furthermore, most industrial cogeneration is on-site and thus avoids transmission losses, reduces energy costs and security vulnerabilities, and improves reliability and power quality. By significantly reducing the environmental footprint of industry, cogeneration plays a central role in enhancing corporate environmental responsibility. While significant potential for expansion of cogeneration capacity exists, it is typically constrained by outdated framework policies for the electricity sector and by electric utilities that perceive cogeneration as a threat to their sales of electricity and, therefore, their revenue. The extent of cogeneration in selected countries is shown in Figure 6.

Power plants and water use

Conventional electric power plants require large amounts of water for cooling. Half the water used is evaporated in the cooling process and the other half is discharged into waterways, often at higher temperatures or in a degraded state. For example, in the United States 39 per cent of available freshwater is used in power supply, 39 per cent for irrigation in agriculture, while only 14 per cent is consumed by public water supply and 6 per cent by industry. Since cogeneration systems do not require water for cooling, they save water and avoid environmental impacts to natural bodies of water.[18]

The petroleum refining industry provides fuel to practically every economic sector with the largest shares going to the transport sector and chemical industry. Refineries themselves are large consumers of energy with approximately 50 per cent of operating costs attributable to energy needs. The United States accounts for about one quarter of all refinery capacity in the world and this industry is the largest industrial energy user in the country. Competitive benchmarking data indicates that most petroleum refineries can economically improve energy efficiency by 10-20 per cent. A number of refining companies have adopted energy management programmes that are yielding significant results. BP has implemented a GHG emission reduction programme that reduced its global emissions to 10 per cent below 1990 levels after just five years. ExxonMobil identified over 200 best practices for processes and equipment that are reducing energy use by 15 per cent. All the refineries operating in the Netherlands participated in Long Term Voluntary Agreements that concluded in 2000 and achieved a total energy efficiency improvement of 17 per cent.

5. Conclusions: Policies for promoting energy efficiency

It seems clear that the new drivers for industrial energy efficiency – in particular, higher energy prices and concerns about climate change – are going to remain with us for some time. The eco-design of more energy efficient industrial products that is being mandated by environmental directives in major markets will only become more stringent over time.

While there is broad experience and history of innovation in industrial energy efficiency policies in developed countries, there remains much potential for further improvement. Moreover, while some developing countries have shown notable improvements in energy efficiency, there is an urgent need for wider diffusion of industrial energy efficiency policies and application of technologies in developing countries.

B. Material efficiency in industry

In the broadest sense, the material intensity of an economy can be defined as the total quantity of all raw materials consumed relative to total production, e.g. tons of raw materials consumed per unit of GDP. This broad concept was developed as a parallel to the concept of overall energy intensity of an economy. The quantity of material consumed is measured as "resource flows" or "total material requirement", a concept pioneered by the World Resources Institute (WRI).[19] This work will be briefly reviewed below.

Reducing the environmental impact of industrial production and moving toward sustainability can also be achieved by changing the materials used, replacing toxic materials or non-renewable resources for example. However, material substitution would need to be analyzed in different and more complex terms, particularly regarding the specific environmental impacts of different materials, so this issue will not be addressed here.

The analysis here will not cover material efficiency in agriculture or fisheries, as they are generally considered outside the industrial sector. Similarly, forestry will not be covered generally, although paper will be covered as it is an important industry and central to recycling programmes. Water efficiency will only be covered briefly as it relates to industrial consumption.

1. Benefits of increasing material efficiency

There are a number of benefits of increasing material efficiency. First, natural resources are conserved, ensuring both that they will be available for future generations and that use of the most accessible and lowest-cost resources will be extended, reducing the cost of production and improving the standard of living. While scarcity of natural resources, other than water and energy, does not appear to impose a substantial restraint on development, conserving those resources does provide benefits.

Second, reducing the demand for raw materials will reduce the impacts of raw material extraction, including both environmental and social impacts. The environmental impacts of mining and primary processing, in particular, can be severe, including water pollution, air pollution and land degradation. Environmental regulation of mining and primary processing has often been less effective than regulation of large-scale industry and the energy sector, in part because mining enterprises tend to be small, in some cases consisting of one mine, so that enterprises can disappear or declare bankruptcy after deposits are depleted, leaving the damage to be cleaned up by others.[20] In the United States, for example, many of the largest Superfund toxic waste sites are metal mines, and mining operations produce a large share of industrial toxic releases. The costs of these environmental impacts are not reflected in market prices of raw materials. Analyses have generally found that the environmental impacts of recycling materials are substantially less than the impacts of extracting the same raw materials. The impacts of raw material extraction will not be examined here, other than to note that increasing material efficiency will reduce such impacts.

Third, energy will be conserved and greenhouse gas emissions reduced. As indicated in the consideration of energy efficiency above, the metals sector in particular is very energy intensive. Recycling of materials can save most of the energy required for refining and processing. Typical energy savings from recycling relative to raw material extraction are estimated at: aluminium 95 per cent, iron and steel 74 per cent, plastic 80 per cent, paper 64 per cent and glass about 10 per cent.[21]

Fourth, increasing material efficiency will reduce the amount of waste material going to landfills or incineration, reducing land use, water and air pollution and other negative impacts from waste handling. Industrial production and consumption are involved in almost all solid waste disposal in developed countries, whether through wastes from extraction of industrial raw materials, wastes from industry, or household or office waste of industrial products. In the United Kingdom, industrial production and consumption account directly for almost one-third of solid waste, with mining and quarrying, and construction and demolition accounting about equally for most of the remaining two-thirds. Within the 33 per cent due directly to industrial production and consumption, 14 per cent is directly from industry, 10 per cent is from commercial sources, and 9 per cent is household waste. Only the 5 per cent of solid waste due to dredging, and a few per cent due to household yard waste (leaves and grass) and food waste would be independent of industrial production. Agricultural residues are generally not included in solid waste statistics, nor are livestock wastes, which are considered liquid waste.[22]

Fifth, and finally, improved collection and recycling of waste, particularly drink containers and plastic bags, could reduce the amount of litter cluttering land and water and in some cases clogging drainage systems. In fact, the desire to reduce litter for aesthetic reasons has been a major driving force behind municipal recycling schemes in many areas.

2. Resource scarcity

Scarcity of natural resources other than water and energy, as noted above, does not appear to be a critical problem for development. Deposits of most mineral resources are fairly abundant relative to demand. As the richest and most accessible deposits have been gradually depleted, improvements in extraction and processing technology have reduced extraction costs, and prices of raw materials have generally trended downwards in recent decades, with short-term fluctuations due to cycles of supply and demand. As a result, there has been little economic pressure for increasing material efficiency.

Since 2004, however, prices of metals have increased substantially, with the IMF metals index increasing to almost three times the 2002 level. This increase in prices has been primarily due to high growth in demand, largely from China. Prices are expected to decline over the next few years as new extraction and refining capacity comes on line in response to high prices. Energy prices are considered more likely to remain high, and since material extraction and refining tends to be energy intensive, particularly for metals, raw material prices are likely to remain somewhat above the prices of recent decades (IMF, 2006). As a result, there is likely to be strong short-term pressure for increased material efficiency and recycling, and more modest long-term pressure.

3. Total material consumption

From an economy-wide perspective, material intensity is measured and monitored through material flow accounting (MFA), a concept developed by the World Resources Institute and elaborated in detail by Eurostat, including the development of a statistical database (Eurostat, 2001).

According to the Eurostat database, overall material consumption, including fossil fuels but excluding water, in the EU-15 amounted to 15.7 tonnes per capita in 2002. In broad categories, this includes, per capita, 7.0 tonnes of construction minerals (sand, gravel, crushed stone), 4.0 tonnes of biomass (food, fodder and wood), 3.7 tonnes of fossil fuels, and 1.0 tonnes of industrial ores and metals. Over the period 1970-2000, this broad measure of material consumption grew closely with economic growth in the lower-income countries of the EU-15 (Spain, Portugal, Greece, Ireland, Italy), keeping material intensity fairly constant relative to GDP, while in the richer countries (Sweden, UK, Netherlands, Belgium, Germany), economic growth has been largely "de-coupled" from total material consumption, leading to a steady reduction in material intensity per unit of GDP. In the UK, Sweden, and particularly Germany, total material consumption has declined over the period. This de-coupling of material consumption from economic growth appears to occur between a GDP per capita of about US$20,000 and US$30,000 (Weisz et al., 2005, pp.19-22).

Analyses to date of total material flows have aggregated mass flows without taking into account the specific environmental impacts of particular flows, due in part to lack of data and techniques for such analysis. A more detailed system of MFA accounts for policy development might take into account both large flows – usually with low specific environmental impacts – and small flows with large impacts, such as heavy metals and hazardous chemicals. Such an analysis has been proposed but would need to include hundreds of different materials and would be a complex undertaking (Eisenmenger, Fischer-Kowalski and Weisz, 2006).

There have been few if any policy efforts focusing on reducing aggregate material flows as such, in part because no single policy could address this broad aggregate, and in part because the different material flows have very different impacts on sustainability and the environment, and policies generally focus on more specific problems.

The main direct driver of overall industrial material efficiency is raw material prices, but general policy measures such as taxes on raw materials to increase prices (other than on fossil fuels) have not generally been used to reduce consumption or increase material efficiency. One exception to this is taxes on construction aggregate in a few countries intended to promote recycling of those materials and reduce landfill. Increased charges for logging on public land, or restrictions on such logging, could increase prices of wood and promote efficiency in wood and paper use, but there has been little use of such instruments for these purposes.

4. Lightweighting

The simplest and most direct form of improving material efficiency in industry is reducing the amount of material that goes into a product, or "lightweighting". The average weight of aluminium cans in the United States has decreased from 20.6g in 1972 to 15.6g today, a reduction of 24 per cent. Glass bottles are now about 25 per cent lighter than they were in 1984. Plastic soft drink bottles made of polyethylene terephthalate (PET) had an average weight of 67g in 1984 and 48g in 2000. Plastic milk jugs made of high density polyethylene (HDPE) weighed 120g in the mid-1960s and 65g in 2000. The thickness of the most common plastic grocery bag has been reduced from 30 microns to 18 microns (Rathje and Murphy, 2001, p.101). This industrial lightweighting has contributed substantially to improving material efficiency in the last few decades and to stabilizing, but not reducing, total material requirements.

However, there is probably limited scope for much more lightweighting (distinct from material substitution) in most products, perhaps with the exception of electronics, a modest but growing component of waste (considered below). With respect to material efficiency, increased recycling generally appears to offer the greatest potential for further progress, with material substitution contributing to eco-efficiency. In addition, industrial lightweighting is driven, at least directly, by internal production economics, production technologies, and raw material prices, with limited influence from public policies. Lightweighting will therefore not be analyzed in detail here.

5. Recycling

Recycling of waste materials back into industrial production, as noted above, not only reduces requirements for the extraction and processing of virgin natural resources, but also saves much of the energy consumed by extraction and processing, and reduces the amount of waste going to landfills or incineration. It is therefore an important contributor to material efficiency, in terms of natural resource requirements, and the component that has been the main focus of public policy.

Recycling is generally more cost-effective for waste from industry and business than for household waste, as industrial and commercial activities generally produce large volumes of relatively uniform waste. Collection and recycling of household waste is less cost-effective because of the high costs of collecting and sorting mixed wastes in relatively low volumes, particularly considering that most households, to a greater or lesser extent, contaminate recyclables with non-recyclable material and throw out recyclables with the general garbage. In the United Kingdom, while recycling of household waste amounted to 6.3 million tonnes in 2003 (22 per cent of household waste), industrial and commercial recycling amounted to 30.7 million tonnes (45 per cent of total industrial and commercial waste).[23]

Economic analyses of municipal recycling of household waste indicate that recycling is often more expensive than landfill disposal (usually excluding externalities), particularly where inexpensive land is available, as in most parts of the United States. Recycling is most cost-effective for aluminium, other metals and paper, and is least cost-effective for plastics and glass. Assessing the costs and benefits of household waste recycling, including all externalities, is rather complex, and different analyses come to different conclusions. Nonetheless, it seems fairly clear that recycling of household waste does reduce consumption of virgin raw materials and thus contributes to material efficiency.

Demand, and therefore prices, for many recycled materials have been low, particularly for the mixed recyclables derived from household waste. This is in part because industries are reluctant to invest in production systems using recycled material, which often differ significantly from systems using virgin raw materials because of uncertainties about availability and price of recycled material and variability in the characteristics of the material. Recycling paper, for example, requires processes for removing ink, staples and other artificial contaminants, but not for removing lignin and other natural contaminants of pulpwood.

It should be noted that household waste recycling is a traditional as well as a recent phenomenon, with a historical gap between the two. In the industrialized countries, until the early to mid-twentieth century, small-scale and informal commercial collection of municipal waste for reuse and recycling (e.g. “rag and bone men” in the United States), was common, sometimes as barter exchange. There were specialized collectors and recyclers for rags, used clothing, paper, scrap metal, and food waste – particularly bones and fat – as well as used but still usable household goods. Industry, both large and small, commonly used recycled materials as inputs. Then, in the early twentieth century, rising wages and standards of living, health and safety concerns, declining prices of virgin raw materials, and new technologies of mass production gradually reduced demand for most recycled materials, and collection of household waste for recycling largely disappeared (Strasser, 1999). Informal waste scavenging and recycling are still common in developing countries, where formal municipal waste collection and disposal systems are very limited. However, modern systems are gradually being introduced, reducing traditional recycling, for better or worse.

While traditional informal scavenging has declined and environmental recycling of household waste has increased over the 20th century, commercial scrap recycling has continued, sometimes in competition with municipal recycling. In the United States, member enterprises of the Institute of Scrap Recycling Industries (ISRI), operating on a purely commercial basis, recycle over 130 million tons of material per year, compared to 79 million tons of household waste recycling.[24]

Reducing solid waste and littering were the main political drivers of the introduction of modern municipal recycling programmes in the 1970s. In the United States, it was estimated that by 1990, there were more than 140 laws related to recycling in 38 states (Rathje and Murphy, 2001, p.200). By 2006, some 9000 communities had introduced collection of separated household waste for recycling, alongside general waste collection, up from one in the 1970s. Some states have now achieved municipal waste recovery rates of about 50 per cent.[25] Figure 7 shows the components of municipal solid waste in the United States, amounting to a total of 245 million tons in 2005. Figure 8 shows the recycling rates for various components – using different categories than figure 7.[26]

In the United Kingdom, where modern household recycling began a little later, recycling, including composting, increased from 11 kg per capita per year in 1991 to 113 kg in 2004 (figure 9). Over the same period, total annual household waste per capita, including recycled waste, increased from 428 kg to 517 kg. Recycling thus accounted for 22 per cent of total municipal waste by 2004. As a result, unrecycled waste declined from a peak of 456 kg per capita in 2001 to 404 kg in 2004.[27]

In OECD countries, all of which now have a variety of recycling programmes, municipal waste recycling rates are increasing and now average over 80 per cent for metals, 40-55 per cent for paper and cardboard, and 35-40 per cent for glass (de Tilly, 2004). Recycling of municipal solid waste, including composting of organic waste, in the EU-15 varies from 4 per cent in Portugal to 64 per cent in the Netherlands. The remainder of the waste goes to either landfill or incineration, with incineration, generally with energy generation, dominating in the Netherlands, Denmark, Sweden, Belgium and Germany, as well as Japan, and landfill in most of the other European countries, as well as in the United States and Canada.[28]

Also affecting industrial material efficiency are product and packaging take-back requirements, also known as "extended producer responsibility", which make industry responsible for their associated waste products, including end-of-life products. These requirements, recently introduced in Europe and Japan (see below), in addition to providing recycled material to the originating industry at no charge beyond that of meeting the take-back requirements, also provide an incentive to design the products to reduce the amount of waste and facilitate recycling. These policies appear to be fairly effective in increasing recycling and, in the case of packaging at least, in reducing waste generation rates. It is still too early to assess their effectiveness in reducing waste generation and recycling through product design.

Charges and restrictions on waste disposal can also promote industrial recycling by increasing the cost of disposal and thus making recycling more economically attractive. In many places in the United States, for example, it is illegal to dispose of automobile lead-acid batteries in landfills. Such batteries must be returned to dealers, making it economical to recover the lead for use in new batteries.

To reduce waste generation and promote recycling generally, particularly from industry and business which pay directly and volumetrically for waste disposal, Denmark in 1987 introduced a landfill tax, which has gradually increased to € 50 per tonne, roughly doubling the cost of landfill disposal. Lower taxes are charged on incineration, particularly for incineration with energy recovery, as that is the preferred option for final disposal in Denmark. As a result of this and other measures, reuse and recycling of waste in Denmark increased from 21 per cent in 1985 to 60 per cent in 2000. The Netherlands also has a high landfill tax, which was increased in 2000 to € 70 per tonne (OECD, 2003).

In the Republic of Korea, following the introduction of a Volume-based Waste Fee System and a Waste Deposit-Refund System, an Extended Producer Responsibility system was introduced in 2003, covering TVs, refrigerators, air conditioners, tires, lubricating oil, metal cans, glass bottles, paper packaging and plastic packaging material. Responsibility was subsequently expanded to cover fluorescent light bulbs and packaging film, and responsibility for electronic products is planned. Under the system, the Ministry of the Environment sets annual recycling obligations for each product and each producer or importer. The producers and importers than submit annual recycling plans and progress reports, and fines are imposed if the obligations are not met.[29]

The growth of recycling programmes in recent decades has, in some cases, created a glut of recycled materials that exceed industrial demand, even if they are free. Indeed, for most materials, recycling of material back to industry is limited by demand more than supply. In 1987, when the state of New Jersey in the United States introduced requirements for municipal recycling, the collection rate for newspapers increased from 50 per cent to 62 per cent, and the price of used newsprint fell from US$45 per ton to minus US$25 per ton, i.e. the collectors had to pay to get rid of it (Rathje and Murphy, 2001, p.206). To increase demand, and therefore prices, for recycled material, and to encourage the introduction of technologies using recycled material as input, some communities have passed laws requiring government offices, and in some cases private businesses, to buy products such as paper with a certain proportion of recycled material. These measures, however, have been difficult to administer and enforce. The fact that waste collection and recycling is commonly the responsibility of municipal authorities rather than national governments can make it difficult to develop national policies or build national markets.

5.1 Metals

Recycling of metals, unlike many other types of recycling, has a long and continuous history as a commercial business, to which modern municipal recycling of household waste makes a modest contribution. And metal recycling makes a major contribution to material efficiency in industry, as well as to energy efficiency. In the United Kingdom, the contribution of recycled metal to total production is: lead 74 per cent, steel 42 per cent, aluminium 39 per cent, copper 32 per cent and zinc 20 per cent. Energy savings from the use of recycled metals were about: aluminium 95 per cent, copper 85 per cent, steel 68 per cent, lead and zinc 60 per cent.[30]

In the United States, the volume of metal scrap recycling, like metal production, is dominated by iron and steel, with about 78 million tons recycled, compared with 2.5 million tons of aluminium, 1.5 million tons of copper, and 1.3 million tons of lead.[31]

In the United States in 2005, the 78 million tons of scrap iron and steel recovered for recycling, represent 76 per cent of domestic production (103 million tons). Most of the recycled scrap was used domestically, but an increasing share, about 17 per cent, was exported, with China as the largest importer. The recycling rate of 76 per cent was up from about 65 per cent in the late 1990s. The major components of scrap steel are vehicles (almost 100 per cent recycled), construction beams (97 per cent recycled), appliances (90 per cent recycled), construction rebars (65 per cent recycled), as well as rail components, machinery and other large items. Municipal solid waste recycling contributed 14 million tons to recycled steel in 2005. A modest but significant growth component of this was steel cans, with the recycling rate increasing from 15 per cent in 1998 to 65 per cent in 2005.[33] The international price of high-grade scrap steel has increased in the last few years to US$300-US$400 per ton in 2006, up from US$100-US$200 a few years ago. The price of basic finished steel products, such as wire rods and rebars, is now about US$400 to US$500 per ton, indicating that a major share of the cost of steel is in mining and refining. The recent price increases have substantially increased the profitability of scrap steel recycling. The increased recycling over the last decade has reduced United States demand for iron ore, as the trends in production and consumption have been generally flat.

Scrap steel is the input for steel-making in the electric arc furnace (55 per cent of steel production in the United States), while iron ore, along with some scrap, is used in the blast furnace and basic oxygen furnace (45 per cent of steel production). Steel production from scrap in the electric arc furnace requires about one-third of the energy required for steel production from iron ore in a blast furnace, reduces air pollution by 85 per cent and water use by 40 per cent.

Aluminium production, including both primary production from bauxite and secondary production from recycled scrap, increased from 16 million metric tons globally in 1976 to 43 million tons in 2005. Aluminium production from recycled material increased from 2.8 million tons to 13 million tons over the same period, increasing from less than 18 per cent of total aluminium production to about 30 per cent. This represented a reduction in the increase in bauxite mining and refining by about 40 per cent. Recycling of aluminium generally provides greater economic benefits than other materials, as primary production from bauxite is highly energy intensive, while aluminium production from scrap can be accomplished with as little as 5 per cent of the energy input. The capital cost of an aluminium recycling plant is about one tenth the cost of a bauxite smelter complex.[34]

In the United States, which accounts for almost half of recycled aluminium, 59 per cent of recycled aluminium was manufacturing scrap recycled within the industry, with 41 per cent coming from post-consumer recycling. About half of the post-consumer recycling consisted of used beverage cans, about 60 per cent of which were recycled, mostly for making new cans. The average aluminium can now contains more than 50 per cent recycled aluminium.

In the United Kingdom, recycling of aluminium cans increased greatly in the 1990s as a result of recycling programmes, from 1,200 tonnes (2 per cent of aluminium can production) in 1990 to 34,400 tonnes (40 per cent) in 2001. Over the same period, the weight of the average aluminium can was reduced from 18.5g to 15.5g (a 16 per cent reduction), making an additional smaller contribution to overall material efficiency. Total consumption of virgin aluminium for beverage cans was reduced slightly, as total production almost doubled, and would have more than doubled had plastic bottles not increased their share of the beverage container market. The recycling rate for other aluminium packaging, mostly aluminium foil, is lower, resulting in an overall aluminium recycling rate of 24 per cent. In addition to recycling into beverage cans, recycled aluminium is used for making lightweight vehicle components. Aluminium recycling in the United Kingdom is lower than in other industrialized countries, largely due to lower rates of household waste recycling.[35]

From 1970 to 2003, the price of aluminium in real terms fluctuated, with an overall downward trend to less than US$1,500 per tonne. As noted above, the increase in recycling during that period, while profitable, was driven more by the desire to reduce waste and litter through deposit-return schemes and household recycling programmes than by shortage of bauxite or high prices for aluminium. Since 2004, the price of aluminium has increased to about US$2,600 per tonne, providing increased incentives for recycling.[36]

Global copper consumption has been increasing steadily, from about 15 million tonnes in 1993 to 20 million tonnes in 2005. The share of recycled scrap, about 30 per cent in 2005, has fluctuated between 30 per cent and 40 per cent since 1970. In absolute terms, recycling of copper scrap increased steadily until 1995 to 6.5 million tonnes, and has since fluctuated in the range of 6 to 6.5 million tonnes. In the United States, about half of the copper consumed is used in buildings, particularly for wiring, with the other half used in electrical and electronic equipment, transportation equipment, and machinery. There is little copper in ordinary household waste. Copper products such as building wiring can have a lifetime of decades in use, limiting the availability of scrap.[37] The overall trend of copper prices from 1970 to 2000 was downward, with the price falling by about half in real terms between 1970 and the late 1990s. Fluctuations in copper prices have tended to be reflected in fluctuations in recycling rates, with recycling rates declining when copper prices fall (Chipman, and Dzioubinski, 1999). However, since 2002, the price of copper has more than quadrupled, from about US$1,500 per tonne to almost US$7,000 per tonne. The scrap price has also increased, substantially increasing the incentive for copper recovery and recycling.

Total world production and consumption of lead has been increasing steadily in recent years, with recycling increasing and primary production declining, in both absolute and relative terms. Recycled lead increased from under 30 per cent of the total in 1976 to almost 60 per cent in 2003. Recycled lead is mostly post-consumer recycled from lead-acid vehicle batteries, which account for about 60 per cent of global lead consumption. Lead-acid batteries account for almost 90 per cent of the lead used and recycled in the United States, where many other uses of lead, such as paint and leaded gasoline, have been banned. Most states legally require recycling of lead-acid batteries and prohibit disposal in landfill. Over 90 per cent of lead-acid batteries from motor vehicles are recycled in the United States, Canada, the United Kingdom and other OECD countries. The energy required for processing recycled lead is about one quarter that for primary lead.[38]

Mining subsidies, often implicit, reduce the cost of mining and the economic incentives for metal recycling. In the United States, for example, an 1872 law still in effect allows hard rock mining enterprises (but not coal, oil or gas enterprises) to buy public land for US$5 per acre and not pay any production royalties to the government. Relative to actual land values, this amounts to an implicit subsidy of about US$500 million per year.[39] In addition, the lack of guarantees for clean-up costs often leaves those costs to the public. The cost of cleaning up some 550,000 abandoned hard rock mining sites in the United States is estimated to be in the range of US$32 billion to US$72 billion.[40] Ensuring that the prices of metal reflect the full costs of mining, including externalities, would increase incentives for recycling.

5.2 Paper and packaging

The United States in 2005 consumed 100 million tons of paper (including cardboard), with 51 million tons (51 per cent) recovered for recycling, up from 92 million tons consumed and 35 million tons (39 per cent) recovered in 1993. The volume of waste paper going to landfill declined from 47 million tons in 1987 to 38 million tons in 2003. Unlike metals, most recycled paper derives from municipal solid waste. Two-thirds of the paper recovered goes back to paper mills, providing 37 per cent of the paper industry's fibre requirements. It is estimated that each ton of paper recycled conserves roughly 17 trees.[41]

Two-thirds of that recycled paper is used for making cardboard (including both smooth paperboard and corrugated packaging), with most of the rest going into tissue, sanitary paper and newsprint. Cardboard generally has a high recycled content, newsprint and tissue have variable amounts, and most high quality printing and writing paper has relatively low recycled content. As a result of this "downgrading" of recycled paper, due to damage to the pulp fibres in the recycling process as well as to contamination of the collected paper, it is estimated that the maximum overall recycled content of paper and cardboard would be 70-80 per cent. Most of the recovered paper not used by paper mills in the United States was exported, with little going to incineration or landfill. As a result of the increased recycling, paper industry requirements for virgin fibre, and the amount of waste paper and cardboard sent to landfills, have been fairly constant, despite steadily increasing total production.[42]

Germany, in 1991, began a programme to reduce and recycle packaging waste, including product and transport packaging, through a Packaging Ordinance that requires manufacturers to pay the cost of recycling the packaging from their products and to achieve a recycling rate of 60-75 per cent, depending on the material. While some companies developed schemes to comply with the Ordinance on their own, many manufacturers joined forces with retail firms and waste collection companies in the German Dual System or Green Dot system in order to reduce costs through economies of scale. Participating manufacturers place a green dot on their packaging and pay the waste collection companies for the green dot packaging they collect for recycling. Packaging recycling in Germany is thus a national programme, rather than a municipal programme as elsewhere. As a result, packaging in Germany declined from about 96 kg per person per year in 1991 to 77 kg in 2002, a reduction of about 20 per cent. Of over 6 million tonnes of packaging waste collected, some 5.3 million tonnes went back to industry for reuse, an 84 per cent recycling rate.[43] At the same time, the printing industry in Germany, in order to avoid regulation, adopted a voluntary quota for the recycling of printing paper, with the quota increasing from 53 per cent in 1994 to 60 per cent in 2000.

The Green Dot programme has been expanded to the European level in response to the 1994 European Packaging Directive and is now operational in 25 European countries with some 130,000 participating enterprises. Participating waste collection programmes are organized in the Packaging Recovery Organization Europe (PRO-Europe). For goods imported from outside Europe, the European importer is responsible for meeting the requirements. As a result, the paper recycling rate in Europe has increased to 55 per cent in 2005, up from 38 million tonnes in 1998 to 46 million tonnes, accounting for over half of the paper produced.[44]

In Japan, efforts to increase corporate responsibility for waste recovery since the mid-1990s have increased paper recovery and reuse rates from about 50 per cent in 1993 to about 67 per cent in 2003 (Bowyer, et al., 2005).

Recycling requirements for paper increase the amount of material available for reuse and reduce its cost, making it more attractive to paper producers. However, increasing recycling requirements in Germany, as in other places, resulted in an initial rapid increase in volumes of recovered paper, which reduced the market price of recovered paper to below zero, i.e. recyclers had to pay producers to accept recovered paper in order to dispose of all of the available supply. Subsequently, the high availability and low price of recovered paper induced producers to invest in production facilities designed for recycled material, which raised prices again (Baumgärtner and Winkler, 2003). In order to increase the market for recycled paper as well as reduce the impact of government paper consumption, the United States Government requires that the paper it procures have at least 30 per cent recycled content. California requires that at least 50 per cent of the newsprint used by each printer and publisher must contain at least 40 per cent post-consumer recycled fibre. In Wisconsin, newspapers are required to use newsprint with a least 35 per cent recycled content. Procurement policies of many private companies also specify recycled content for paper and packaging. These policies have encouraged companies to invested in systems for recycling paper, increasing the demand and price for recovered paper, and making recycling more economical.

The economic incentive for paper recycling is undermined by subsidization of timber extraction. The United States Forest Service spends about US$34 million per year on building, maintaining and subsidizing roads in national forests, which are used without charge by logging companies. Charging industry for these services would increase the price of virgin timber and paper made from it, increasing the demand for recovered paper.[45]

The cost of paper and other wood products also depends on the price wood harvesters pay for the right to harvest the wood, sometimes called "stumpage fees". In the United States, most harvested timber comes from private land, with prices set by supply and demand, but a significant share of wood comes from public land. In recent years, environmental concerns have reduced or stopped timber sales from public lands, reducing supply and increasing prices, particularly for construction lumber.

It should also be noted that waste paper products contribute to energy recovery from incineration of municipal solid waste, replacing fossil-fuel energy generation. As renewable biomass energy, it also reduces net emissions of greenhouse gases. In some circumstances, using waste paper as an energy source may be more sustainable than recycling. Logging residues are also burned for process heat in paper production, and increasingly for district heating and power generation through combined heat and power (CHP) systems, reducing fossil fuel consumption. In Finland, wood fuels, mostly from logging residues, provide 21 per cent of total primary energy. This can also be considered as an increase in material efficiency in forest industries, including pulp and paper (UNEP, 2006).

More general questions of sustainable forest management and forest productivity, deforestation, timber trade, "industrial" tree farming, biodiversity, carbon sequestration and other such questions, all of which affect timber prices, will not be addressed here, as they are more part of discussions on forest management than industrial efficiency.

5.3 Beverage containers

In the United States, a deposit-return system was introduced in the state of Oregon in 1972, with a 5 cent deposit required on all bottles and cans of beer and carbonated soft drinks. As a result, over 90 per cent of the beverage containers covered were returned, although the rate gradually declined to 82 per cent in 2002, in part due to increasing consumption in public places where recycling was less convenient. In states without such "bottle bills", about 30 per cent of beverage containers are recycled. In addition, the share of roadside litter consisting of beverage containers in Oregon declined from 40 per cent to 10 per cent, which was a primary purpose of the law.[46] Ten other states have since introduced bottle bills. Other countries with deposit-return systems for various kinds of beverage containers include Canada (1970), Netherlands (1974), Finland (mid-1970s), Sweden (1984), Denmark (1989), Switzerland (1990), Austria (1990) and Kiribati (2004).[47]

Some countries have other charges or restrictions, in some cases in addition to deposits, on various types of beverage containers. In Finland a system of taxes, together with deposits, ensures that 81 per cent of beer and soft drinks are sold in refillable glass or PET bottles, with most of the rest recycled in other ways. Norway has a tax on all packaging, including non-refillable beverage containers, with partial exemption depending on recycling rates. In Denmark, domestic beer and soft drinks must be sold in refillable glass or plastic bottles, with standardized beer bottles allowing reuse without sorting by brand. The German Ordinance on Packaging Waste (1993) requires that at least 72 per cent of most beverages be sold in refillable bottles. Sweden required (1984/1994) that aluminium cans and PET bottles must achieve 90 per cent recycling or face a ban, leading to the adoption by bottlers of standard bottles to facilitate reuse.[48]

5.4 Plastics

Some plastics, notably PET (polyethylene terephthalate) and HDPE (high density polyethylene), both of which are used for bottles and other containers, can be reused by the plastics industry and are included in many municipal recycling schemes. Recycling plastic, compared to virgin plastic production from natural gas or petroleum feedstock, reduces energy and water consumption by 70-80 per cent, including conservation of the chemical feedstock in their production, and substantially reduces air pollution.[49] Globally about 4 per cent of oil and gas is used as feedstock for plastics production, and another 4 per cent (equivalent) is used for energy for plastics processing.

In the United Kingdom, a total of 4.7 million tonnes of plastics are consumed annually, 35 per cent of which consists of bottles, containers and other packaging, with building and construction accounting for another 23 per cent. About 3 million tons is disposed of as waste, of which about 7 per cent is recycled. Some 24,000 tons of plastic bottles are recycled, amounting to 5.5 per cent of the bottles sold.[50]

In the United States in 2004, some 500,000 tons of PET bottles were collected, representing about 20 per cent of PET bottle production. The volume collected has increased slightly in recent years, but the recycling share has declined from 40 per cent in 1995 to 20 per cent in 2002, apparently because people are consuming more drinks in small containers away from home (Royte, 2005, p.177). In Europe, 665,000 tons of PET bottles were collected in 2004, representing a 30 per cent collection rate.

Used PET can be recycled into new plastic bottles – Coke and Pepsi have committed to using 10 per cent recycled material in their PET bottles – as well as for fibrefill for winter coats and sleeping bags, polyester carpeting, fleece jackets, or plastic strapping. One-third of the used PET collected in the United States is exported to China, with the amount doubling between 1995 and 2004. Clean recycled PET flakes now (November 2006) fetch US$600-US$700 per tonne on the international market, providing a strong incentive for recycling. In the German Green Dot packaging recycling programme, reuse of recovered plastic by industry has increased from 51 per cent of the recovered plastic in 2001 to 63 per cent in 2005 (Schedler, 2006).

In the United States in 2002, about 2 million tons of HDPE bottles and containers were used, with 370,000 tons recycled, for a recycling rate of about 20 per cent. This was a dramatic increase from 40,000 tons recycled (a 5 per cent rate) in 1990. Recycled HDPE is used in the production of bottles (28 per cent), plastic film (17 per cent), pipes (15 per cent), shipping pallets (14 per cent), and plastic lumber (11 per cent), with the remaining 15 per cent going to other uses or exported, mostly to Asia. Recycled HDPE thus replaces both petroleum and wood in production. The increase in recycling since 1990 has been accompanied by longer-term light-weighting of HDPE bottles, with the weight of a one gallon milk container, for example, declining from 95g in the 1970s to 60g in 2000.[51]

Recycling of HDPE from municipal solid waste, like most plastics, is not generally profitable, as the cost of collecting household HDPE is about US$1000-US$1400 per ton, with processing costs of about US$120 to US$250 per ton, while used HDPE currently (November 2006) fetches about US$200-US$400 per ton on the international market, depending on quality.[52]

While the tonnage of PET and HDPE recycled has increased rapidly, it has been from a low base and is not keeping up with the rapid increase in total PET and HDPE production and consumption. Plastic recycling is therefore not reducing in absolute terms the amount of petroleum and energy consumed in its production. On the other hand, the increase in PET and HDPE production and consumption has, in part, replaced the use of glass, paper cartons and other plastics, so a full examination of the evolving impact of PET and HDPE would need to take into account the impact of substitution as well as the impact of recycling. It should also be noted that waste plastics contribute to energy recovery from waste incineration.

Some countries have also adopted policies to reduce the use of plastic bags. In response to such bags littering the landscape and clogging drains, South Africa has banned bags under 80 microns thick (standard supermarket bags are 18 microns), Bangladesh and Taiwan (province of China) have banned free distribution of bags by stores, and Ireland has imposed a 15 cent charge for each bag (Royte, 2005, p.193).

The recycling rate for plastics remains very low relative to other materials, providing a large potential for substantial increases in material efficiency, with benefits for reducing energy consumption, waste, air pollution and greenhouse gas emissions.

5.5 Glass

Recycled glass, which is collected in some municipal recycling programmes in the United States and not in others, is used to make new bottles, for fibreglass, and for road construction aggregate. The inclusion of some recycled glass reduces the energy required for glass-making. In general, however, the benefits of improving material efficiency in glass production are less than those for other materials. Waste is reduced, but the energy saved is small, and the raw material, sand, is abundant and cheap everywhere (Royte, 2005, p.266).

5.6 Electronic waste

Computers and other electronic equipment, which contain lead, mercury, chromium, cadmium, barium, beryllium, PVCs, brominated flame retardants and other toxic elements as well as plastic, copper, glass and other materials, are of growing concern with respect to waste. In the United States, the volume of e-waste entering the waste stream is uncertain, with estimates ranging from 1-4 per cent of municipal solid waste. It is estimated that about 70 per cent of the heavy metals in landfills come from electronic waste, and Silicon Valley in California has become seriously contaminated with toxic waste from electronics production. Observations indicate that the amount of electronic equipment, particularly computers, that is discarded is much less than the numbers being replaced by consumers, suggesting that most households are storing old computers and other electronic devices, and that the quantity entering the waste stream will soon increase rapidly. A large quantity of discarded computers and other electronic products from the United States, Japan and the Republic of Korea is exported to China and other developing countries in Asia for recycling, often under unsafe conditions.[53]

To reduce electronic waste going to landfills and incinerators, the European Union in 2003 adopted a Waste Electrical and Electronic Equipment (WEEE) Directive requiring industry, starting in August 2005, to take responsibility for recovering and recycling electronic waste without charge to consumers. On products sold before 2005, the costs of collection and recycling are to be shared by all producers, while for later products, producers will be responsible for collecting and recycling their own products. This is intended not only to promote recycling, but also as an incentive to producers to design products to reduce waste and facilitate recycling.[54] In the Netherlands, Norway, Sweden and Switzerland, the purchase price of some electronic items includes an advance disposal fee to fund recycling.

Japan, as part of its Basic Plan for a Recycling Society, has been developing legal requirements for recycling. The 1998 Home Appliance Recycling Law came into effect in 2001. By 2003, collection of used air conditioners, TV sets, refrigerators and washing machines had increased by about 20 per cent, metals were recovered for recycling, and CFCs (ozone depleting substances and greenhouse gases) were recovered for disposal.

In the United States, the Environmental Protection Agency (EPA) estimates that electronic waste amounts to 2.5 million tons per year, of which about 10 per cent is recycled. National law regulates disposal of electronic equipment by businesses and government agencies, but only six states require recycling of electronic equipment by households. A growing number of municipalities are taking action to ban the disposal of electronic equipment in landfills, but without adequate infrastructure for recycling.[55]

Recycling of electronic products can include recovery of gold, platinum, silver, copper and steel, as well as plastic and glass, although little such recovery is now done. Usable electronic components can be recovered by disassembly, plastic and steel can be recovered by mechanical shredding, and other metals can be recovered by incineration and/or chemical extraction. In China, copper wire is recovered by burning the plastic covering, while acid baths are used to recover precious metals, but under very unsafe conditions. Electronic products can be considered as ores in that circuit boards contain much higher concentrations of gold, copper and other metals than natural ores, and fewer polluting contaminants. However, recovering these materials is not currently economical. Recycling of these materials could be encouraged by simple design changes to facilitate component extraction and material recovery.[56]

5.7 Automotive waste

The EU has adopted a Directive on End-of-Life Vehicles to reduce waste going to landfills and promote recycling. By 2007, 85 per cent by weight of every new vehicle must be made from recyclable components, up from the 75 per cent metal that is now recyclable.[57]

In 1995, the Danish government entered into an agreement with a number of organizations on a take-back scheme for used tires, with a goal of recycling 80 per cent of scrap tires. Previously most scrap tires ended up in landfills. A consumer charge of about US$1 per tire on purchase is used to subsidize enterprises that collect tires and convert them into rubber granulate. In 1999, the take-back rate reached 87 per cent.[58]

5.8 Construction and demolition waste

The building sector accounts for a large amount of waste (mostly concrete and bricks from demolition), accounting for an estimated 10 per cent to 44 per cent of total solid waste in various OECD countries. As it is difficult to reduce the amount of material in buildings without reducing performance, the potential for waste reduction is mainly from recycling materials. Currently the estimated recycling rate ranges from 5 per cent to 90 per cent in various OECD countries, with much of the waste going to engineering fill or road foundation, where the quality of the material is less important than in the case of building materials. The annual volume of waste generated by demolition also depends on the lifetimes of buildings before replacement, with average lifetimes of commercial buildings in OECD countries ranging from 31 years in the United States to 62 years in the United Kingdom.

To reduce the volume of demolition waste going to landfill or incineration, some OECD countries have imposed mandatory separation of demolition waste and restrictions on the disposal of recyclable construction material to landfills. In some cases, demolition contractors must get disposal plans approved before demolition can begin, which also helps to protect against illegal dumping. These measures are often in addition to general landfill taxes and virgin material taxes (e.g. aggregate taxes), which increase the economic incentive for recycling. In Denmark and the Netherlands, both of which have had, since 1997, strict limitations on the disposal of recyclable demolition waste in landfills, landfill taxes, permission requirements for demolition, and other incentives for recycling, 90 per cent of demolition waste is recycled. In Japan, the Construction Recycling Act came into effect in 2002, requiring the sorting of debris from demolition to facilitate recycling of stone debris for road and building construction, and reuse of lumber for particle board, paper or energy generation.[59]

Builders, however, are often hesitant to use recycled materials due to concerns over quality. Furthermore, due to low levels of recycling, recycled materials are often less conveniently available than virgin material available through construction supply houses, and transport costs are relatively high for low-cost construction materials. As part of efforts to address this problem, the United Kingdom, in 1998, established an internet-based Material Information Waste Exchange to allow contractors with unwanted materials or wastes to find others who could use them.

5.9 Water

In considering industrial water efficiency, it is important to distinguish between water withdrawals and water consumption, although the terms are often used interchangeably. Commonly used figures indicate that in developed countries, industry, including power-generating plants, accounts for 59 per cent of water withdrawals. Most of this water, however, is used by power plants, which use it for cooling purposes and then return it to watercourses slightly warmer, but available for other use downstream. Actual consumption of water, with evaporation ultimately making it unavailable for further use, is much lower.

In the United States, power plants account for 39 per cent of total water withdrawals (131 billion gallons per day), but only 3 per cent of that (3.5 billion gallons per day) is actually consumed, amounting to 4 per cent of total water consumption. Industry and mining, excluding power plants, account for 8 per cent of withdrawals (28 billion gpd) and 5 per cent of water consumption (4.5 billion gpd). Domestic and commercial uses account for 10 per cent of withdrawals (34 million gpd) and 7 per cent of consumption. Agriculture (as well as livestock and landscape watering) actually consume most of the water withdrawn for those purposes.[60] The major problem with industrial water use in relation to sustainable development is not water consumption in this sense, but pollution of the water that is used and returned to watercourses. In other words, water quality is more important than water efficiency.

In the United States, since the 1970s, there have been large increases in water efficiency in terms of production per unit of water withdrawn, particularly in the industrial sector. Total water withdrawals by non-agricultural businesses, including the mining, industrial and commercial sectors, but excluding power plants, declined by 38 per cent from 1970 to 1995, from about 45 billion gallons per day to about 31 billion, while output increased by 69 per cent. From 1980 to 1995, reductions of about 10 per cent were achieved in the much larger water withdrawals for thermal-electric power plant cooling and for agricultural irrigation. These reductions in absolute volume are substantially larger when calculated on a per capita basis or per unit of GDP (Hawken, Lovins, and Lovins, 2000, pp.216-217, 225).

Improving water efficiency in industry through reducing withdrawals is generally achieved by recycling water within the facility, with pollution treatment as necessary to make the water reusable. While reducing water withdrawals and reducing pollution, it also reduces the water returned to watercourses by about the same amount, and thus does not make any more water available to other users downstream. In the case of cooling water, the only effect is to reduce the warming of the watercourse from which the water is withdrawn and to which it is returned.

The recycling of water and reduction in water withdrawals by industry in recent years has generally been in response to public policy measures limiting the discharge of polluted water. Rather than treating water to public standards and discharging it, industry has found it more economical to recycle the used water, treating it sufficiently to meet internal water quality requirements. Where industry pays for water from municipal water systems, a reduction in water withdrawals also saves money for the enterprise, so increasing water prices will also promote water efficiency in this sense.

Pulp and paper mills have been heavy users and polluters of water. As an example of more efficient water use, a German manufacturer of paper products for packaging was able to reduce water withdrawals by over 90 per cent by treating and recycling wastewater, withdrawing only enough new water to compensate for evaporation and the water content of the paper products. The resulting water withdrawals were 15 to 20 times less than the recent German norm (Hawken, Lovins, and Lovins, 2000, p. 225).

Reducing water withdrawals can be particularly important in urban areas in dry regions where competition for clean freshwater is particularly intense. In India, water withdrawals for the Bhilai Steel Plant in Madhya Pradesh State, which suffers severe water scarcity, were reduced from 17,000 m^3/hr to 3000 m^3/hr, or from 52 m^3 per ton of steel to 10 m^3 per ton, through a water conservation project undertaken in response to drought conditions in 1988. This was achieved through rainwater harvesting, treatment and recycling of wastewater, reduction in water leakage, improved operation and maintenance of the pumping system, and reducing water use in landscaping. The water conservation measures required improved water quality monitoring and treatment to meet water quality requirements for process water and waste water discharge (UNEP, 1998a).

In some cases, reducing water withdrawals and pollution discharges can be combined with measures to recover useful material from process water, thus increasing material efficiency. In Concepción, Chile, for example, fish processing companies that produced fishmeal were a major source of organic water pollution going into the sea. Faced with impending effluent regulations, the Fisheries Association of 16 companies found that the fish wastes in the effluent could profitably be recovered, increasing fishmeal production while reducing water withdrawals and pollution. Improved pumps reduced losses in pumping fish from ship to shore, while substantially reducing water use and damage to the fish. Screens captured fish particles from the effluent and returned them into the fish processing system, further reducing fish losses and pollution. The new system reduced organic pollution (chemical oxygen demand) by 85 per cent while increasing productivity and reducing water withdrawals, such that the investment paid for itself within two years. In urban coastal situations such as this, where water is withdrawn from municipal water supplies and discharged to the sea, reducing water withdrawals can increase the amount of freshwater available for other uses (United Nations, 1999, p.34).

Use of wastewater for industrial purposes that do not require water of drinking quality can increase the availability of clean water for uses which require the highest quality. In Chennai (formerly Madras), India, which suffers from severe and increasing water scarcity, Madras Fertilizers Ltd. has switched from using potable groundwater that can be used for other municipal purposes to partially treated municipal wastewater, which the company treats further. The company uses about 20 million litres/day, about two-thirds for cooling and one-third for process water and general uses. The company installed advanced wastewater treatment technologies to remove biological oxygen demand (BOD), hardness and ammonia, together with reverse osmosis to remove dissolved solids to ensure adequate water quality. This has freed about 14 million litres/day of drinking water for use in Chennai (UNEP, 1998b).

In general, as noted above, the primary issue concerning industrial water use is water quality rather than water efficiency. As the issue of freshwater management and water quality protection is a very broad issue beyond the scope of this chapter, it will not be considered further here.

6. Conclusions: Policies for promoting material efficiency

As indicated above, a variety of public policies have been used effectively in many countries, most often in developed countries, to promote material efficiency. These policies include legal and regulatory requirements, taxes and charges, other economic incentives, and supportive public services.

The broadest and best known set of policies for promoting material efficiency in the production-consumption cycle is to promote recycling of used or waste material back into the industrial production system. While recycling of industrial metal, and to a lesser extent paper and plastic, has long been a profitable commercial activity without policy support, this commercial recycling has, since the 1970s, been supplemented by policy-driven municipal waste recycling, which has made a modest contribution to metal recycling, and a much larger contribution to paper recycling.

Since the 1970s, many communities have set up recycling programmes as part of household waste collection services. Households are required to separate recyclable material, most often cans, bottles, paper and yard waste, from other household waste. The municipality collects the material for recycling, usually does further sorting, and sells the saleable material to commercial recyclers who sell it to industry. Household separation is often legally mandatory and households can be fined for putting recyclables in the regular waste, but enforcement is difficult and voluntary participation is generally good although imperfect.

Some communities, in the United States, Republic of Korea and other countries, have introduced financial incentives for waste reduction and recycling through volume-based waste collection charges ("pay-as-you-throw") that exclude recycled material. Households may pay for collection of a certain volume of waste on a regular basis, or may buy pre-paid bags or tags for their waste. A few programmes are weight-based but these are more complicated to manage. Recyclable material is placed in separate containers for which there is no charge. They appear to be effective in increasing recycling, but their effect on waste reduction is unclear. As they are mostly volume-based, they tend to increase household waste compaction more than reduction.

Deposit-return systems for beverage containers were among the earliest policy-driven recycling efforts. Those systems have been very effective, greatly increasing the recycling of containers, often up to rates of around 90 per cent. In various countries, such schemes have applied to various types of containers (cans, glass bottles, plastic bottles), and various types of beverages (soft drinks, beer, water, milk, wine). The deposits have ranged from about US$.05 to US$.50. They require arrangements for collection and return of deposits and handling of returned containers, a burden imposed on retailers, wholesalers and bottlers, leading to opposition to such systems. In addition to promoting recycling, such schemes can provide some income for informal scavengers, who can make a substantial contribution to the effectiveness of the system.

In some cases, such as in Denmark, deposit-return schemes have been complemented and supported by requirements for the use of refillable glass or plastic bottles. Such containers may be heavier and stronger than non-refillable containers to survive the rigours of recycling, and hence will conserve raw materials only if they are effectively recycled. Again, such requirements have sometimes aroused the opposition of bottle manufacturers, bottlers, distributors and retailers who have to fund and manage the system.

In most cases, the deposit-return scheme, including specification of the containers covered, deposit amounts and other arrangements, is mandated by public policy. In some cases, however, as in extended producer responsibility systems, public policy establishes general requirements for recovery and allows industry to set up the mechanisms, which may include deposit-return mechanisms.

While most deposit-return schemes have applied to beverage containers, they have also been used for lead-acid batteries in Germany and in some states of the United States, for old cars in Norway and Sweden, for appliances and tires in the Republic of Korea, and for pesticide containers in the United States (state of Maine).

Landfill taxes have been used in some countries to increase the price of waste disposal and provide an economic incentive for recycling. These are effective more for businesses and industries that pay directly for waste disposal than for households. They may be particularly effective for demolition debris, which involves a large volume of waste. Landfill taxes have been used in Denmark, Netherlands and the United Kingdom to substantially increase the cost of disposal to landfill. Denmark and the Netherlands, as well as Japan, also have regulatory restrictions on the disposal of demolition debris to landfill in order to promote recycling of construction material for roads and buildings. The United Kingdom has an "aggregate tax" to reduce quarrying of construction aggregate and promote recycling.

Bans on disposal to landfills are used as policies to compel recycling. In the United States, many communities ban disposal of lead-acid batteries to landfills and require their recycling. In many cases, almost 100 per cent of lead-acid batteries are recycled.

Extended producer responsibility (EPR) requirements have been used in a number of countries, in particular in the EU and Japan, as an effective means to promote recycling of a variety of materials and products, including packaging, old vehicles, electronics, appliances and batteries. In contrast to municipal recycling programmes, extended producer responsibility puts the cost and management responsibility for collection and recycling on industry, although some programmes also provide for government involvement and support. EPR also provides an incentive for industry to design products to be more recyclable, although its effectiveness for this purpose is unclear.

Increasing recycling means not only increasing the supply of recovered material, but also increasing the demand from industry. In the United States, ten state governments have established mandatory recycled-content requirements for products produced in or imported into the state, including newsprint, trash bags, glass and plastic containers and fibreglass. In Belgium, disposable beverage containers are subject to a tax unless they have 50 per cent or more recycled content.

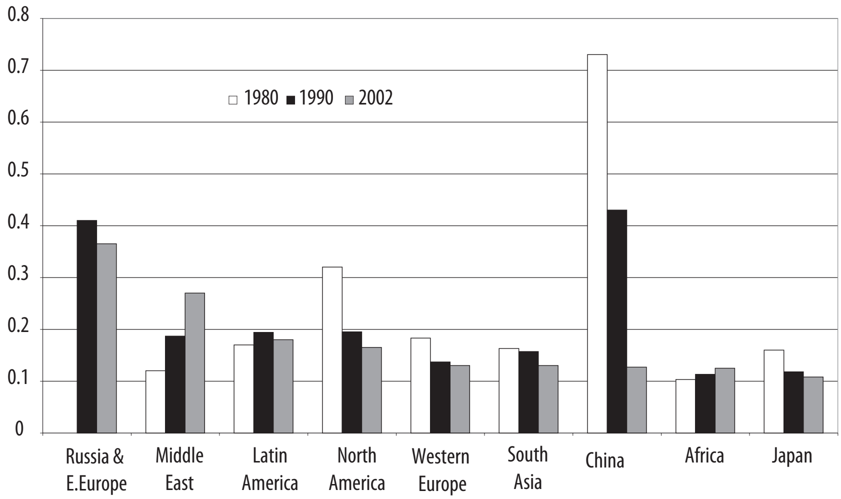
Public procurement also provides a public mechanism for promoting recycling by increasing demand for recycled material. The United States Federal Government and many local authorities require procurement of recycled-content paper for themselves and contractors, as well as more general recycled-content requirements for other procurement. To assist government procurement agents, the US Environmental Protection Agency has developed standards for recycled content for a range of products and lists of products meeting those standards. Such requirements for government procurement not only increase demand directly, but also provide a model and incentive for procurement requirements by industry, other institutions and households. Making government standards and databases publicly available also helps other institutional consumers in buying recycled products. This increases demand for recycled material, which raises prices, which encourages commercial recycling and helps pay for municipal recycling.

Governments can also intervene in some cases to increase the prices of raw materials, thus increasing the economic incentive for industrial material efficiency and recycling. In many countries, for example, wood comes in part from national forests, and policies controlling access to those public resources can increase the price of wood products, including paper. Restricting logging on public land, reducing government support for logging operations, or increasing "stumpage fees" will tend to increase the cost of virgin paper and other wood products.

Stronger environmental laws on mining, including requirements for remediation of the land after mining is exhausted, with financial guarantees to cover the costs of environmental damage and clean-up, would internalize the environmental costs of mining, raise the price of minerals, and promote material efficiency and recycling.

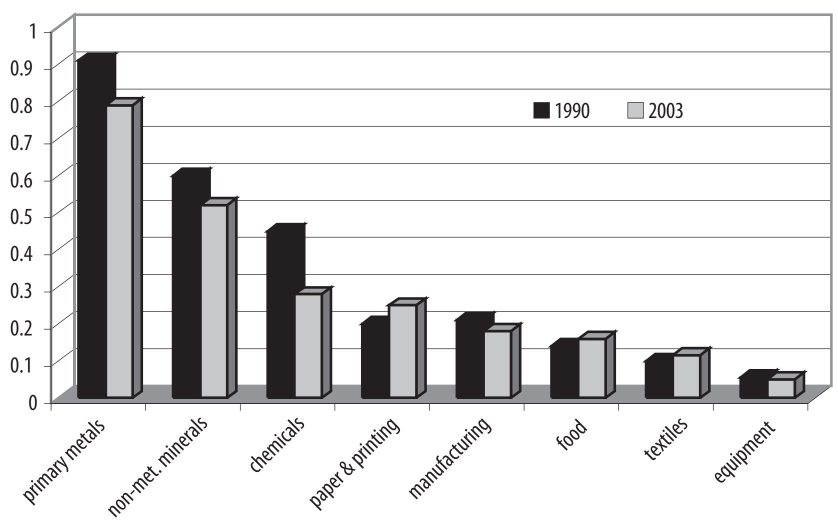
Finally, governments can facilitate industrial recycling by promoting waste exchanges and industrial ecology that link industries producing a certain type of waste product with other industries that can use those waste products as inputs.

Figure 1. Regional variation in industrial energy intensity
[Kg oil equivalent/industrial output (1995 US $ ppp)]



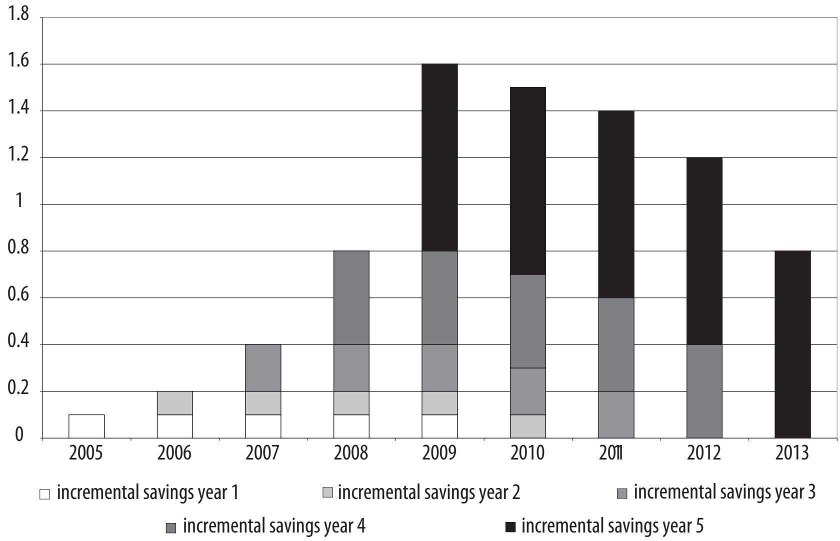
Source: World Energy Council using data from Enerdata.

Figure 2. Energy intensities by sub-sector in the EU-15
(Kg oil equivalent per euro, 1995)



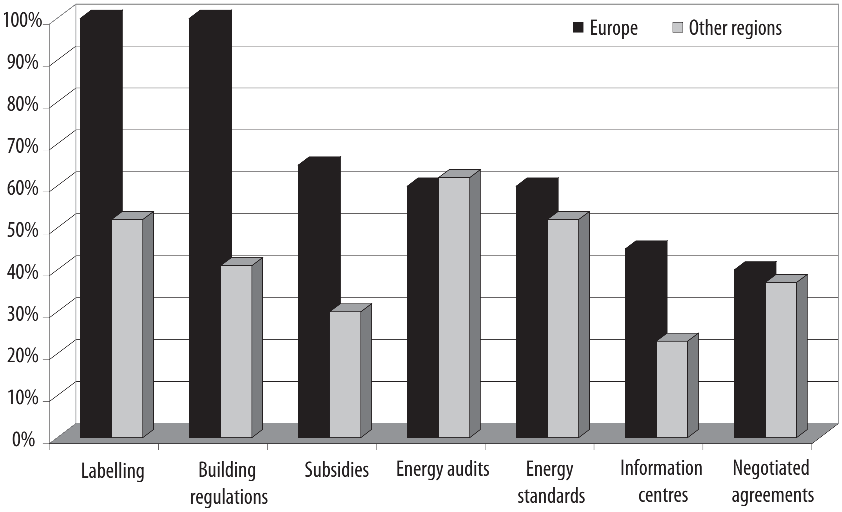
Source: Odyssee and Enerdata.

Figure 3. White certificate electricity savings target and evolution of savings in Italy (million tons of oil equivalent)



Source: Odyssee and Enerdata.Source: Pavan, M., White Certificates can foster ESCO development. In: ESCOs in Europe conference, 6-8 October 2005. Vienna.
Note: The data for this chart were compiled by WEC-ADEME from a survey of 63 countries. Energy savings projects are expected to contribute to the achievement of targets for up to five years, therefore the chart begins in 2005 and ends in 2013.

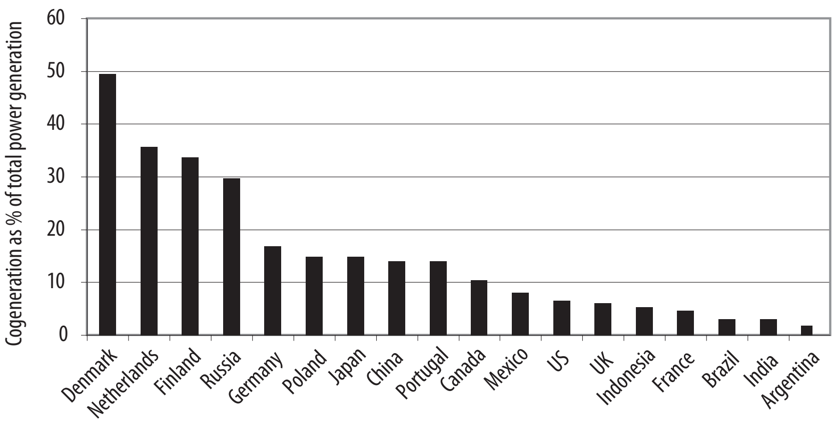
Figure 4. Energy efficiency policies – most frequent measures (% of countries where policy is used)



Source: François Moisan, Energy efficiency: a worldwide review -- Indicators, policies and evaluation, World Energy Council – French Agency for Environment and Energy Management, 2006.

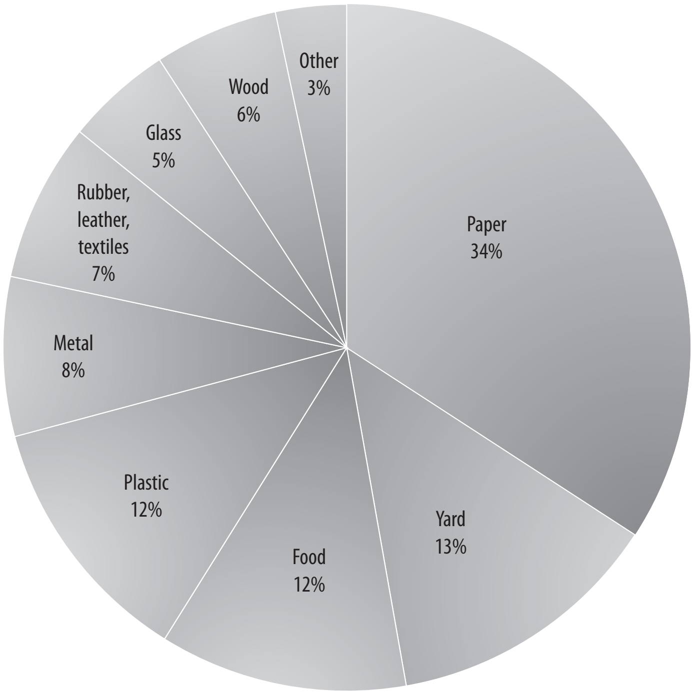
Figure 5. Energy efficiency labels for motors from China, Colombia, Singapore and Thailand, respectively.

Figure 6. Extent of cogeneration in selected countries in 2004



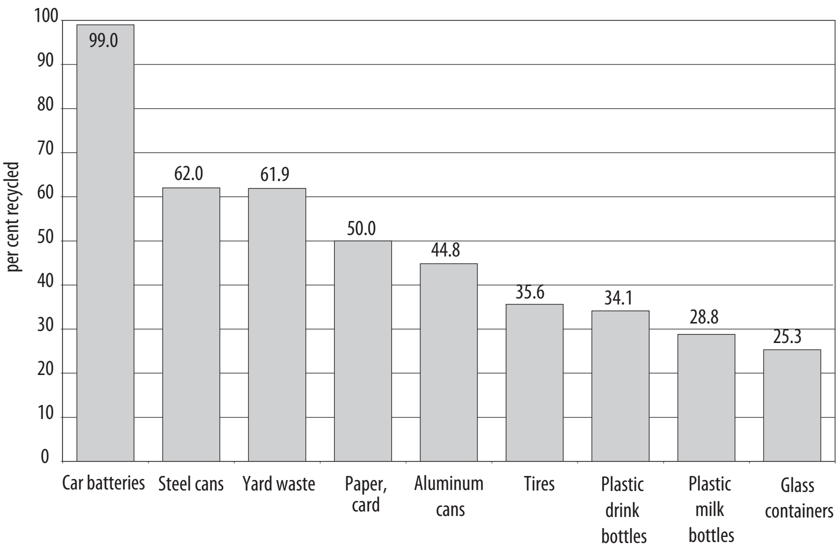
Source: World Survey of Decentralized Energy 2005, World Alliance for Decentralized Energy, 2005.

Figure 7. Municipal solid waste (United States, 2005)



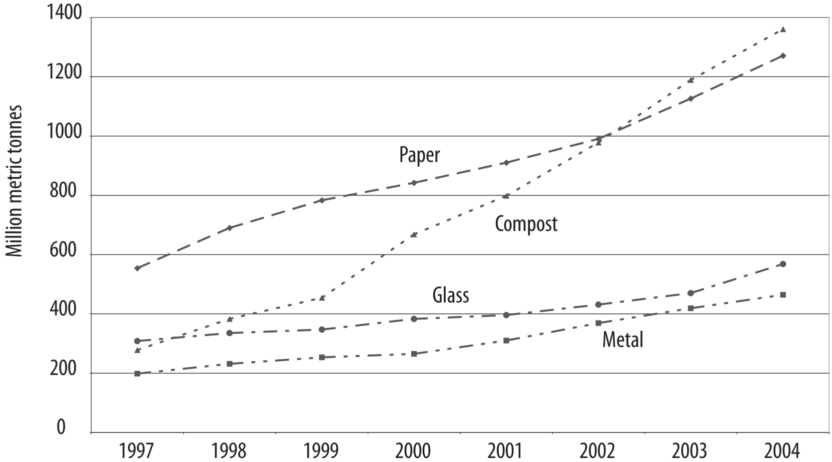
Source: US EPA, Municipal Solid Waste (*www.epa.gov/msw/facts.htm*).

Figure 8. Recycling rates - selected materials (United States, 2005)



Source: US Environmental Protection Agency (November 2006), Municipal Solid Waste: Basic Facts (*www.epa.gov/msw/facts.htm*).

Figure 9. Household waste recycling, UK



Source: Defra (*www.defra.gov.uk/environment/statistics/waste/download/xls/wrfg15.xls*).

Table 1.
Pollution levies in selected countries

Country	Administrative/ civil penalties	Criminal penalties	Remarks
Australia	X		Currently under review
Austria	X	X	Fines depend on income of violator
Czech Rep.		X	In addition to fines and imprisonment, other sanctions may be imposed
Denmark	X	X	Civil penalties are under consideration
Finland		X	Fines set according to discretion of court
France		X	Fines doubled for repeat offenses
Germany	X	X	In corporate cases, managers may be imprisoned
Greece	X	X	
Hungary		X	Imprisonment is typically applied
Ireland	X	X	Fines unlimited under some statutes
Portugal	X	X	
Slovakia	X	X	Fines doubled for repeat offences
Spain		X	
Netherlands	X	X	Civil penalties are under consideration
UK	X	X	Civil penalties are under consideration
USA	X	X	Fines vary depending on statute; doubled for repeat offences

Source: adapted from Price et al. (2005).

Table 2.
Taxes and fiscal incentives promoting industrial energy efficiency in selected countries

Country	Taxes or Fees			Fiscal Incentives				
	Energy or CO_2 tax	Pollution levy	Public benefits charge	Subsidies or grants	Subsidized audits	Soft public loans	Innovative private funds	Technology tax relief
OECD								
Australia		A/C	X	X	X		E	EX
Austria	X	A/C, CR		X	X		E	
Canada					X		E, RF	AD
Denmark	X	CR		X	X			
Finland	X	CR		X	X		E	
Fraance	X	CR		X	X		GF, IF	
Germany	X	AC, CR		X	X	X	E, IF	EX, R
Hungary		CR		X	X	X	E, GF	
Italy	X			X	X		E	R
Japan		X		X	X		E	AD, R
Korea					X	X	E	R
Mexico				X	X	X	E, IF	
Netherlands	X	CR		X	X			AD, R
UK	X	CR		X	X	X	E, VC	R
USA		A/C, CR	X	X	X	X	E	EX
Non-OECD								
Brazil					X		GF, RF	R
Egypt					X	X	E	R
Indonesia					X			
Jordan				X	X	X	E	R
Philippines					X	X	E	R
Thailand				X	X	X	E, RF	
Tunisia				X	X		E	

Sources: World Energy Council 2004, Energy Efficiency: A Worldwide Review — Indicators, Policies, Evaluation*, London; Galitsky, Price and Worrell (2004).*
Obs.: X = program exists; A/C = administrative/civil penalties; CR = criminal penalties; E = ESCOs; GF = guarantee fund; RF = revolving fund; VC = venture capital; AD = accelerated depreciation; R = reduction; EX = exemption.

Table 3.
Selected voluntary/negotiated agreements with industry

			Incentives								Penalties			
Country	Agreement	Program years	Government and public recognition	Information	Assistance and training	Energy audits	Financial assistance & incentives	Emissions trading	Relief or exemption from regs & taxes	Reduced/ avoided energy/ GHG taxes	More stringent env. permitting	Increased reg's	Penalty/ fee	Energy or CO_2 tax
Completely voluntary														
Australia	Greenhouse Challenge	1996-present	X	X	X									
China (Taipei)	Energy Auditing Programme	2002-2020	X	X	X	X								
Finland	Promotion of Energy Conservation in Industry	1997-present	X	X	X	X	X							
Korea, Rep.	Energy Conservation & Reduction of GHG Emissions	1998-present	X	X	X		X							
USA	Climate Vision	2003-present	X	X	X	X								
With threat of regulations or taxes														
France	AERES Negotiated Agreements	2002-present	X		X			X					X	
Germany	Agreement on Climate Protection	2000-2012							X	X				
Japan	Keidanren Voluntary Action Plan on the Environment	1997-present	X											
Netherlands	Benchmarking Covenants	2001-2012	X	X			X		X		X			
Energy/GHG taxes or regulations														
Canada	Large Final Emitters Programme	2003-2012		X	X	X		X	X			X	X	
Denmark	Industrial Energy Efficiency	1993-present		X	X	X	X			X				X
New Zealand	Negotiated Greenhouse Agreements	2003-2012						X		X				X
Switzerland	CO_2 Law Voluntary Measures	2000-2012						X		X				X
UK	Climate Change Agreements	2001-2013	X	X	X	X	X	X		X				X

Source: Price (2005).

Table 4. Overview of industrial sector energy efficiency program products and services of industrialized countries

	Australia	Canada	Denmark	EU	France	Germany	Japan	Netherlands	Norway	Sweden	Switzerland	UK	USA
Audits/assessments							X	X		X		X	X
Benchmarking			X			X		X	X			X	
Case studies	X	X		X			X	X	X	X		X	X
Demonstration: commercialized technologies			X		X	X	X	X			X	X	
Demonstration: emerging technologies		X		X	X			X		X			X
Energy awareness promotion materials	X	X	X		X		X		X	X	X	X	
Fact sheets	X			X						X	X	X	X
Industry profiles		X		X				X	X				X
Reports/guidebooks	X	X		X		X	X	X	X	X	X	X	X
Tools and software	X	X	X	X		X		X	X			X	X
Verification	X	X		X	X	X		X	X				X
Visions/roadmaps	X	X					X	X		X			X

Source: Galitsky, Price and Worrell (2004).

Table 5. Improvement in performance of four South American electricity distribution companies

Performance criteria	Peru Luz Del Sur	Argentina Edesur	Argentina Edenor	Chile Chilectra
Year privatized	1994	1992	1992	1987
Energy sales (GWh/y)	+19%	+79%	+82%	+26%
Reduction in energy losses	-50%	-68%	-63%	-70%
No. of employees	-43%	-60%	-63%	-9%
Customers/employee	+135%	+180%	+215%	+37%
Net receivables (days)	-27%	-38%	n/a	-68%
Provisions for bad debts, % of sales	-65%	-35%	n/a	-88%

Source: Bacon and Besant-Jones (2001).

Notes

1 International Energy Agency, http://www.sourceoecd.com.

2 International Energy Outlook 2006, U.S. Energy Information Administration, 2006.

3 World Energy Council, http://www.worldenergy.org/wec-geis/publications/reports/weepi/introduction/definition.asp.

4 International Energy Outlook 2006, U.S. Energy Information Administration, 2006.

5 Climate Change 2001, Intergovernmental Panel on Climate Change, 2001.

6 Johnson, J., 1998, "EPA Fines Engine Makers", http://www.ttpnews.com/members/printEdition/0000164.html.

7 International Energy Agency,

http://www.iea.org/textbase/pamsdb/detail.aspx?mode=gr&id=24.

8 Countries that responded to the survey include: the EU-25 countries, Russia, Turkey, Canada, USA, Mexico, Costa Rica, Brazil, Chile, Colombia, Peru, China, Rep. of Korea, Japan, Thailand, Myanmar, Malaysia, Singapore, Indonesia, Philippines, Australia, New Zealand, Iran, Jordan, Algeria, Egypt, Tunisia, Morocco, Mali, Mauritania, Guinea, Cote d'Ivoire, Ghana, South Africa, Botswana, Kenya, Tanzania.

9 Collaborative Labeling and Appliance Standards Program,

http://www.clasponline.org/disdoc.php?no=171.

10 "Energy Efficient Motor Driven Systems", European Copper Institute, http://www.eurocopper.org/eci/jsp/index.jsp?idx=48.

11 Lawrence Berkeley National Laboratory, http://china.lbl.gov/china_industry-iee-best.html.

12 Canadian Energy Efficiency Agency: best practices,

http://www.energyefficiency.org/.

13 Press article, "Cautious optimism? The Indian Power Sector", Sachin Kerur, Dec. 2005 http://www.pinsentmasons.com/media/1096940727.htm.

14 "Power" EquityMaster, Quantum Information Services Private LTD. http://www.equitymaster.com/research-it/sector-info/power/.

15 Prem K. Kalra, " Transmission and distribution loss minimization", Indian Institute of Technology, Kanpur,

http://www.electricityindia.org/dca_stanford/presentations/Prem_Kalra.pdf.

16 "Power" EquityMaster, Quantum Information Services Private LTD. http://www.equitymaster.com/research-it/sector-info/power/

17 World Survey of Decentralized Energy 2005, World Alliance for Decentralized Energy, 2005.

18 Combined Heat and Power White Paper, American Council for an Energy Efficient Economy, 2006.

19 World Resources Institute (1997), Resource Flows: The Material Basis of Industrial Economies. http://materials.wri.org/resourceflows-pub-2742.html.

20 US Government AccountabilityOffice (GAO) (17 August 2005), Environmental Liabilities: EPA Should Do More to Ensure That Liable Parties Meet Their Cleanup Obligations. Report GAO-05-658, www.gao.gov/htext/d05658.html.

21 Worldwatch Institute (November 2006), Beverages: The Price of Quenching our Thirst. www.worldwatch.org/node/1479.

22 UK Department for Environment, Food and Rural Affairs (DEFRA) (November 2006), e-Digest Statistics About: Waste and Recycling. www.defra.gov.uk/environment/statistics/index.htm.

23 UK Department for Environment, Food and Rural Affairs (DEFRA) (November 2006), Key Facts About Waste and Recycling. www.defra.gov.uk/environment/statistics/waste/kf/wrkf03.htm

24 Institute of Scrap Recycling Industries, Statement of ISRI Chair Joel Denbo to Congress, Sept. 2005. www.isri.org

25 USEnvironmental Protection Agency (November 2006), Municipal Solid Waste: Recycling. www.epa.gov/msw/recycle.htm. See also Royte, Elizabeth (2005), Garbage Land: On the Secret Trail of Trash. Little Brown & Co., New York, p.264.

26 US Environmental Protection Agency (November 2006), Municipal Solid Waste: Basic Facts. www.epa.gov/msw/facts.htm.

27 UK Department for Environment, Food and Rural Affairs (DEFRA) (November 2006), Key Facts About Waste and Recycling. www.defra.gov.uk/environment/statistics/waste/kf/wrkf04.htm.

28 UK Department for Environment, Food and Rural Affairs (DEFRA) (November 2006, e-Digest Statistics About: Waste and Recycling, www.defra.gov.uk/environment/statistics/index.htm

29 Ministry of Environment, Republic of Korea (November 2006), Waste and Recycling. eng.me.go.kr/docs/index.html

30 British Metals Recycling Association (November 2006), What is Metals Recycling. www.recyclemetals.org/whatis.php

31 Harmony Enterprises (November 2006), Non-Ferrous Recycling.

www.harmony1.com/recycling/nonferrous.cfm

32 Steel Recycling Institute (November 2006), Steel Recycling Rates at a Glance: 2005. www.recycle-steel.org. See also Royte (2005).

33 MEPS International Ltd (November 2006), World Steel Prices. www.meps.co.uk.

34 Alupro (November 2006), Facts and Figures.

www.alupro.org.uk/facts%20and%20figures.htm

35 UK Department for Environment, Food and Rural Affairs (DEFRA) (November 2006), e-Digest Statistics About Waste and Recycling: Aluminium. www.defra.gov.uk/environment/statistics/waste/wraluminium.htm. See also Aluminum Packaging Recycling Organization (Alupro) (November 2006), Facts and Figures. www.alupro.org.uk/facts%20and%20figures.htm

36 Aluminum Packaging Recycling Organization (Alupro) (Sept 2006), www.alupro.org.uk/facts%20and%20figures.htm. See also Chipman and Dzioubinski (1999).

37 Copper Development Association (November 2006), The US Copper-base Scrap Industry and its By-products.

www.copper.org/resources/pub_list/pdf/scrap_report.pdf.

38 Lead Development Association International (November 2006), Lead Information. www.ldaint.org/information.htm. See also Chipman and Dzioubinski (1999). (1999)ww.un.org/esa/desa/papers/1999/esa99dp5.pdf.

39 Grassroots Recycling Network (November 2006), Welfare for Waste. www.grrn.org/reports/w4w/ExecSum.pdf

40 Green Scissors (November 2006), Cutting Wasteful and Environmentally Harmful Spending. www.greenscissors.org/publiclands/1872.htm.

41 US Environmental Protection Agency (November 2006), Municipal Solid Waste: Basic Facts. www.epa.gov/msw/facts.htm.

42 Paper Industry Association Council (November 2006), 2005 Recovered Paper Annual Statistics. www.paperrecycles.org.

43 The Green Dot (2005), www.gruener-punkt.de.

44 Confederation of European Paper Industries (July 2006), Europe Global Champion in Paper Recycling. www.paperchain2000.org.uk/news/06/pr0307erpcfigs.pdf

45 Green Scissors 2004 Report: Cutting Wasteful and Environmentally Harmful Spending. Friends of the Earth, Taxpayers for Common Sense, and US Public Interest Research Group. www.greenscissors.org/publications/gs2004.pdf.

46 Oregon Department of Environmental Quality (November 2006), The Oregon Bottle Bill: Fact Sheet.

www.oregondeq.com/wmc/pubs/factsheets/sw/OregonBottleBill.pdf.

47 Container Recycling Institute (November 2006), Bottle Bill Resource Guide. www.bottlebill.org/index.htm

48 Container Recycling Institute (November 2006), Bottle Bill Resource Guide. www.bottlebill.org/index.htm

49 Waste Online (November 2006), Plastics Recycling Information Sheet. www.wasteonline.org.uk/resources/InformationSheets/Plastics.htm

50 Waste Online (November 2006), Plastics Recycling Information Sheet. www.wasteonline.org.uk/resources/InformationSheets/Plastics.htm

51 Miller, Chaz (2001), Profiles in Garbage: High-Density Polyethylene. Waste Age, July. images.wasteage.com/files/121/ArtPackSample.pdf. See also Toto, Deanne (2004), Consumers of Recycled PET and HDPE are Hungry for More Material. Recycling Today, July.

52 Miller, Chaz (2001), Profiles in Garbage: High-Density Polyethylene. Waste Age, July. images.wasteage.com/files/121/ArtPackSample.pdf. See also Toto, Deanne (2004), Consumers of Recycled PET and HDPE are Hungry for More Material. Recycling Today, July.

findarticles.com/p/articles/mi_m0KWH/is_7_42/ai_n6124430.

53 WorldWatch Institute (2004), State of the World 2004, pp. 44-45. See also US Environmental Protection Agency (November 2006), eCycling. www.epa.gov/epaoswer/hazwaste/recycle/ecycling.

54 Europa (November 2006), Waste Electrical and Electronic Equipment. europa.eu.int/scadplus/leg/en/lvb/l21210.htm

55 Vitello, Paul (2006), Clearing a Path from Desktop to Recycler. New York Times, 11 Nov. 2006.

56 US Government Accountability Office (GAO) (November 2005), Electronic Waste. www.gao.gov/new.items/d0647.pdf.

57 Europa (November 2006), Waste Management.

europa.eu.int/scadplus/leg/en/s15002.htm.

58 Danish Ministry of Environment and Energy (1995), Environmental Administration in Denmark, Chapter 8, Environmental Requirements for Consumers. www.mst.dk/udgiv/Publications/1995/87-7944-324-9/html/8.htm.

59 Japan Ministry of the Environment (November 2006), www.env.go.jp/en/.

60 US Environmental Protection Agency (November 2006), National Trends in Water Use. www.epa.gov/OW/you/chap1.html.

Bibliography

Bacon, R. W. and J. Besant-Jones (2001), Global Electric Power Reform, Privatization and Liberalization of the Electric Power Industry in Developing Countries, World Bank.

Baumgärtner, S., and R. Winkler (2003), Markets, Technology and Environmental Regulation: Price Ambivalence of Waste Paper in Germany. Ecological Economics, Vol. 47, p.183-195.

Bertoldi, P. and S. Rezessy (2006), Tradable Certificates For Energy Savings (White Certificates), Theory and Practice, European Commission, Directorate-General, Joint Research Centre, Institute for Environment and Sustainability.

Bowyer, J., J.Howe, P. Guillery and K. Fernholz (2005), Paper Recycling in the United States: How Are We Doing Compared to Other Nations. Dovetail Partners Inc.

Chipman, R., and O. Dzioubinski (1999), Trends in Consumption and Production: Selected Minerals. DESA Discussion Paper No.5, United Nations.

Eurostat (2001), Economy-wide Material Flow Accounts and Derived Indicators: A Methodological Guide.

Farinelli, U. et al. (2005), "White and Green": Comparison of market-based instruments to promote energy efficiency, Journal of Cleaner Production 13.

Galitsky, C., L. Price and E. Worrell (2004), "Energy Efficiency Programs and Policies in the Industrial Sector in Industrialized Countries", LBNL-54068, Lawrence Berkeley National Laboratory, USA.

de Tilly, S. (2004), Waste Generation and Related Policies: Broad Trends Over the Last Ten Years: The Economics of Waste, OECD.

Eisenmenger, N. M. Fischer-Kowalski and H. Weisz (2006), Indicators of Natural Resource Use and Consumption, in Moldan, B., T. Hak and P. Bourdeau (eds.), Assessment of Sustainability Indicators, Washington, D.C., SCOPE, Island Press.

Herz, R. (2005), "Sector Eléctrico Colombiano: Hacia la Profundización de un Esquema de Competencia Efectiva y Participación Privada", ENERCOL.

Hawken, P., A. B. Lovins, and L. H. Lovins (2000), Natural Capitalism: Creating the Next Industrial Revolution, Chapter 11, Aqueous Solution. Back Bay Books.

IMF (2006), World Economic Outlook, Chapter 5, “The Boom in Non-Fuel Commodity Prices: Can It Last?”,

www.imf.org/Pubs/FT/weo/2006/02/index.htm.

OECD (2003), Environmentally Sustainable Buildings: Challenges and Policies. OECD, Paris.

OECD (2000), Electricity Market Reform.

Oikonomou, V. and Patel, M., 2004. An Inventory of Innovative Policies and Measures for Energy Efficiency. Phase 1 of the EU SAVE “White and Green” Project. Utrecht, The Netherlands: Universiteit Utrecht.

Price, L. (2005), "Voluntary Agreements for Energy Efficiency or GHG Emissions Reduction in Industry: An Assessment of Programs Around the World", 2005 ACEEE Summer Study on Energy Efficiency in Industry.

Price, L., C. Galitsky, J. Sinton, E.Worrell, and W. Graus (2005), Tax and Fiscal Policies for Promotion of Industrial Energy Efficiency: A Survey of International Experience, LBNL-58128.

Rathje, W. and C. Murphy (2001), Rubbish: The Archeology of Garbage. University of Arizona Press, Tucson, p.101.

Rezessy, S., P. Bertoldi and A. Persson (2005), “Are Voluntary Agreements an Effective Energy Policy Instrument? Insights and Experiences from Europe”, 2005 ACEEE Summer Study on Energy Efficiency in Industry.

Royte, E. (2005), Garbage Land: On the Secret Trail of Trash. Little Brown & Co., New York.

Schedler, M. (2006), PET Bottle Recycling Status Report. Resource Recycling, February.

Singh, J. and C. Mulholland (2000), “DSM in Thailand: A Case Study”, World Bank/ESMAP Program.

Strasser, S. (1999), Waste and Want: A Social History of Trash. Metropolitan Books, New York.

UN-DESA (forthcoming), Case Studies of Market Transformation.

UNEP (2006), Bioenergy in Finland. www.unep.org/GC/GCSS-IX/Documents/FINLAND-bioenergy.pdf.

UNEP (1998a), Integrated Water Conservation: Bhilai Steel Plant, India. Sourcebook of Alternative Technologies for Freshwater Augmentation in Some Asian Countries, UNEP/DTIE/IETC.

UNEP (1998b), Reclaimed City Sewage as Industrial Water: Madras Fertilizers Ltd., Madras, India, UNEP/DTIE/IETC.

United Nations (1999), Business and the UN: Partners on Sustainable Development. United Nations, New York, p. 34.

World Energy Council (2001), Energy Efficiency:A Worldwide Review.

Worrell, E. and C. Galitsky (2005), “Energy Efficiency Improvement in the Petroleum Refining Industry”, 2005 ACEEE Summer Study on Energy Efficiency in Industry.

Weisz, H., F. Krausmann, C. Amann, N. Eisenmenger, K.-H. Erb, K. Hubacek, and M. Fischer-Kowalski (2005), The Physical Economy of the European Union: Cross-Country Comparison and Determinants of Material Consumption, Social Ecology Working Paper 76, Institute for Social Ecology, Klagenfurt University, Austria.