Technologies for Reducing Stationary Energy Use

Climate Change Working Paper No. 6

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Climate Change Project Working Paper Series

March 2006

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1. Introduction

The IEA Reference Scenario assumes that the efficiency of energy use – the amount of energy needed to provide a given amount of energy service – will continue to improve at a pace similar to that of the past three decades. Because most of the energy-using capital stock has a long life, technological advances can affect the average efficiency of equipment and appliances in use only very gradually.

In stationary energy uses in the industrial, commercial and residential sectors, progressive improvements in energy efficiency are assumed to occur as a result of ongoing technological advances. For example, the growing deployment of integrated building designs, which incorporate efficient lighting, heating and cooling systems, will reduce energy consumption per square metre of office space in new office buildings. Energy efficiency standards and labelling programs already in place will continue to encourage more efficient equipment and appliances in these sectors. However, these efficiency improvements will be very gradual, because of the slow rate of replacement of energy-capital stock, especially buildings.

Efficient and clean end-use technologies can have important emissions-reducing effects because of their broad impact throughout the energy economy. They reduce the use of both direct fuels and electricity, thereby reducing emissions from the power-generation sector as well as from end-use sectors. For example, the IEA/EU Experts Group projects that, when advanced end-use technologies are available at lower cost than in the reference case, primary energy consumption is reduced by almost 7 per cent in both the United States (by 2020) and the European Union (by 2030). Carbon emissions are reduced by 7.3 per cent in the United States (by 2020) and by 8.1 per cent in the EU (by 2030).

In the most optimistic case, the IEA/EU Experts Group found that significant advances in the performance and cost of both supply and demand technologies led to stabilisation of CO_2 emissions in the EU in 2030 to the level of 2000. In the United States, the same conditions did not stabilise emissions but they did significantly moderate them.

Table 1 provides a detailed breakdown of energy use and the associated GHG emissions by sector for the advanced economies in 2000. It should be noted that the data for GHG emissions are direct emissions only. Where fossil fuels are the energy source used, they are included in both energy consumption and GHG emissions because they give rise to direct emissions. However, where electricity is the energy source, it appears in energy consumption but not in GHG emissions because electricity does not give rise to emissions at the point of use. The emissions associated with electricity production and consumption, which indirectly are stimulated by the use of electricity in final energy consumption, are accounted for in energy production.

Of the energy consumption sectors identified in Table 1, commentary on technology is handled in the following way in this document:

- transportation is covered in Paper 5;
- emissions from energy use in industry is covered in the first half of this paper;
- the residential and services sectors give rise to emissions that mainly relate to the buildings sector, and are discussed in the second half of this paper;
- agriculture et al. gives rise to GHG emissions in relation to both energy processes (of fairly small importance) and non-energy processes (more significant) – both are discussed in Jolley (2006);
- other energy consumption mainly relates to military use and is briefly discussed in CSES (2004); and
- as this report covers only emissions from energy consumption, non-energy related GHG emissions arising from industrial processes are not discussed, but are covered in Jolley (2006).

Table 1. Energy Consumption and Associated GHG Emissions in Advanced Economies, 2000, Share of Total Final Energy Consumption

Sector	Energy Consumption	GHG Emissions
Transportation	31.4	46.1
Industry	33.7	29.7
Residential	17.9	13.4
Services	11.7	7.5
Agriculture, Forestry and Fishing	1.5	2.0
Other Energy Consumption	0.8	1.3
Non-Energy Uses	3.0	0.0

Source: CSES (2004).

2. Industrial Processes

Industry Technologies

Process integration is of critical importance in achieving increased energy efficiency in industry. Other technologies common to several industries that are capable of considerable development include motors, separation processes, electro-technologies, superconductivity, advanced energy conversion processes in the long term, and resource recovery and utilisation. Industry-specific technologies particularly relevant to emissions reductions are notable in the ferrous metals, aluminium, cement, pulp and paper and chemical industries.

Process Integration

Current Status of Process Integration

Process integration is the term used for a collection of strategies, methods and tools that focus on the efficient use of resources (energy, raw materials, water and capital) on a systems level (the reference for what follows is Gundersen (2003).

The best-known and most widely applied process integration method is pinch analysis. It was originally developed to facilitate optimal heat recovery between heat sources and heat sinks. Pinch Analysis was based on thermodynamics and initially applied to heat recovery (the efficient recovery or re-use of heat), but it has also been applied to mass transfer (e.g. the exchange of mass through absorbers or extractors), wastewater minimisation, and the optimisation of the hydrogen distribution system in oil refineries.

Process integration applies to most sectors in the process industries, including petroleum refining, chemical manufacturing, food and beverage production. The scope of process integration methods has broadened considerably since the early 1980s when the emphasis was on heat recovery. Today, process integration can be also be used for heat and power systems, utility systems, distillation systems, reactor systems, and even water management and wastewater treatment systems. Process integration is also expected to move into batch processing of such products as pharmaceuticals, resins and dyes.

Heat Recovery in the New Design of Continuous Processes

The single most important industrial application area for Process Integration is heat recovery. There are four phases of Pinch Analysis in the design of heat recovery systems for both new and existing processes:

1. Data extraction, which involves collecting data for the process and utility system. The focus is to identify the need for heating, cooling, boiling and condensation in the process.
2. Targeting, which established figures for best performance in various respects. Targets can be established for minimum energy consumption (external heating and cooling), fewest number of units (process/process heat exchangers, heaters and coolers), and minimum total heat transfer area. By combining these three target areas it is possible to obtain figures for total annual cost.
3. Design, where an initial heat exchanger network is established. The design of heat exchanger networks in various industries is primarily carried out using the Pinch design method. State of the art commercial software packages for heat exchanger network design are available. The basic method focuses on minimum energy consumption while using the fewest possible units. Extensions of this method also minimise the total heat transfer area.
4. Optimisation, where the initial design is simplified and improved in terms of cost-effectiveness. The initial heat exchange network, while minimising three key attributes, does not necessarily minimise total annual cost. The

final optimisation seeks to optimise any trade-off that exists between cost and physical efficiency.

Heat Recovery in Retrofit Design of Continuous Processes

While in the early days of Process Integration methods developed were related to the design of new plants, most of the current projects in industry are trying to make the most out of existing facilities. Typically, these projects are related to improved operation, removal of plant bottlenecks, improved efficiency with respect to energy and raw material utilisation, and the introduction of new technology into an existing process.

In this context, the term retrofit is used for projects trying to reduce energy consumption in the most economic way. The economy of most energy saving projects (cost of new equipment verus reductions in operating cost) is not good enough to include the losses in production if the plant has to be stopped for a period of time while the modifications are installed. Thus, the timing of retrofit projects into regular plant maintenance periods is extremely important. Further, the best retrofit projects are the ones that combine pure energy savings with more general plant modifications.

Retrofit design differs from grassroots design in a number of ways. To begin with, existing designs will incorporate certain features that may impede the subsequent realisation of improved heat recovery that cannot be completely removed, but only improved by smaller or larger process modifications. As a result, the optimal heat exchanger network after retrofit is likely to be quite different from the optimal grassroots design.

A second difference has to do with data extraction. Typically, for a new design there will be data on material and energy balances available from either manual derivations or simulation models. Unfortunately, such models may not always be available for an existing plant. Measurements are often not complete and not reliable. Design data are often outdated after plant modifications. Simulation models may not always reflect the actual behaviour of plant. As a result, data reconciliation is important in retrofit projects.

Thirdly, targeting in the retrofit situation is far more difficult than for grassroots design. This is because a number of different changes can be made to the heat exchanger network in order to reduce energy consumption. Typically, these modifications include the addition of a new heat exchanger, the expansion of an existing heat exchanger, changing internal aspects of heat exchangers, modifying piping on one or both sides of the exchanger, and moving heat exchangers to a new location. Most of these retrofit actions will change the operating conditions for many of the heat exchangers, and a rigorous rating exercise is required to evaluate whether an existing unit will be able to operate in the new situation. The cost function for the retrofit operation will exhibit a discontinuity whenever a heat exchanger switches from being large enough to become too small for the new operation. It is the targeting of the new capital investment (in retrofit) that becomes the principal area of difficulty.

Heat Recovery in Batch Processes

Batch processes have several advantages compared with continuous processes. While continuous processes are designed to serve basically one major purpose for 15-20 years, batch processes typically consist of more general-purpose equipment, which makes such plants far more flexible. This becomes increasingly important in a world of high value products with shorter lifetime. By its very nature, however, batch processes cannot reach the same degree of utilisation of the equipment as continuous processes. Typically, time is lost in a number of operations such as feeding, unloading, cleaning, etc. Time analysis of the operation of such plants (also called scheduling) is therefore extremely important. The time aspect is also a key factor when studying heat recovery of such processes.

In general terms energy cost is small compared with the cost of equipment and raw material for a majority of batch processes. However, in some cases the energy system may be responsible for bottlenecks in such plants, and in quite a few batch industries energy cost is considerable.

The most important difference between batch and continuous processes when studying heat recovery is the time aspect in batch processes where a certain amount of heat is available between specified temperatures, and also between specified times. Thermal energy in such plants has two qualities, temperature and time. An important consequence of this difference is the need for heat storage where the two streams do not co-exist in time.

Advances in Process Integration

Reactor Systems

There has been a considerable activity on reactor systems in the research community. Research topics include the heat integration of reactors, their appropriate placement, the optimal design and operation of complex chemical reactor networks, the synthesis of optimal chemical reactor networks with simultaneous mass integration, and the development of novel multiphase reactors using a systematic design framework.

Heat Exchanger Networks

The most important development on heat exchanger network design has been the combined use of conceptual targets from Pinch analysis with optimisation methods such as mathematical programming. The most recent development is the identification of hypertargets – promising regions for the final design. In this approach, there is development from very simple mathematical models in the early phase to more complex models in the final design stage. Computer software is an absolute requirement in order to apply these new combined or hybrid methods for heat exchanger networks in grassroots and retrofit situations. Such software is not at present generally available.

Advanced Methods for Utility Systems

New variations on the basic methodology for heat recovery have been developed to deal with the mixing of hot and cold utilities such as flue gas for a furnace or gas turbine, various condensing steam levels, hot oil circuits, cooling water, air (for cooling), and refrigeration cycles. Methods have also been developed to analyse the integration of heat pumps into an existing heat exchanger network. Applications of process integration to total sites has been one of the major developments during the past decade.

Analogies to the Heat Recovery Pinch

The heat recovery Pinch concept has been applied through the use of analogies to other areas of process design. These analogies have produced advanced technologies that have already found significant industrial application. These applications include wastewater minimisation, the minimisation of other forms of waste, and the use of hydrogen in oil refineries and petrochemical plants.

Other Technologies Common to Several Industries

Numerous other efficient technologies could reduce energy intensity and emissions in industry. Many of them are specific to individual industries, such as pulp and paper manufacturing, chemical processing or glassmaking. Others are common to several industries. Some examples of the latter are given below. The main reference is IEA (2000).

High Efficiency Motors

High-efficiency motors, drives and motor-driven systems hold significant potential for reducing emissions in the near term. Energy-efficiency opportunities in these systems derive not so much from the replacement of older motors with high-efficiency models as from energy-conscious design throughout the system. The system includes power supply lines, controls, motor feed cables, the electric motor, the drive and transmission system, and the driven load. Each of these system elements may present an opportunity to conserve energy. Efficient technologies are available on the market. Power electronic switching devices and micro-electronics have made electronic adjustable speed drives increasingly popular and have brought down their price. Adjustable speed drives are available in a large variety of designs.

Relevant research is focused on energy assessments of motor-driven systems and the potential of innovations that facilitate energy conservation. Significant research is being undertaken in relation to motor-driven systems in the advanced economies and in China.

High Efficiency Separation Processes

High-Efficiency Separation Processes such as membrane processes, freeze crystallisation and better system controls, have significant potential to reduce emissions attributable to industry in the near term. Industrial separations recover, isolate and purify products of virtually every industrial process. Today’s separation processes include distillation, extraction, drying, absorption, adsorption, crystallisation, membrane-based technologies and stripping. Such processes account for a large share of energy consumption in industry. Improvements in this area are applicable across a wide range of industries. Most of the research on separation systems has been focusing on distillation based systems, with some efforts also in ways to improve energy consumption in evaporation systems.

Advanced End-Use Electro-Technologies

Advanced end-use electro-technologies for industrial end-use applications hold promise for near-term emissions reduction. These technologies can replace many fossil-fuel-based combustion processes in industry. Examples include infrared heating, drying and paint curing; ultra-violet curing; radio-frequency and microwave heating and drying; electron beam processing for metal welding and hardening; induction heating; laser-based technologies; and industrial heat pumps. Electro-technologies in general promise less energy use, less material waste, less pollution and better product quality. They can also provide greater compatibility with advanced sensors and controls, computer controls, and decentralised manufacturing operations. Many electro-technologies are available today and in use in the process industries.

Superconductivity

Superconductors can transform several areas of industry through applications such as:

1. Current transport and energy storage without loss.
2. Generation of very large magnetic fields through persistent currents, leading to magnetic levitation and suspension which enable the development of ‘frictionless’ motors, bearings, flywheels and trains.
3. Josephson junction-based superconducting electronics in a form which combines this quantum effect and the quantisation of magnetic flux and could lead to the development of very fast and low energy consumption digital devices (IEA 2005a).

The IEA Implementing Agreement on High-Temperature Superconductivity has as its objective the improvement of the efficiency with which energy is used in industry, by increasing the knowledge of cost-effective new technologies and system layouts for increased productivity, better product quality, and improved energy efficiency and sustainability IEA 2005b).

Long Term Energy Conversion Processes

In the longer term, the opportunity to influence new plant design, and R&D to develop advanced technologies for specific processes and crosscutting needs, can result in even greater reductions in emissions. Novel concepts such as integration of industrial facilities with other plants and with facilities for power supply and waste management could lead to ‘zero-emission’ systems.

The efficiency of energy conversion processes in industry can be improved by incorporating the best available technologies in a systems approach, particularly for new plants. In the longer term, fuel cells and gasification of biomass and in-plant residues (such as black liquor in the forest products industry) are likely to have a large impact.

In addition to the energy conversion improvements mentioned above, developing new, more efficient processes can also substantially reduce emissions from energy use in industrial processes. Such processes can encourage new, higher-quality products while generating less waste and fewer undesirable by-products. Opportunities exist to improve process efficiency via advances such as more selective catalysts, further developments in advanced separations, improved materials and improved electric motor systems. A particularly attractive longer-term opportunity is the use of biotechnology and bio-derived chemicals and materials.

Increased fundamental understanding in enabling sciences such as chemistry, metallurgy and biotechnology will allow the development of novel manufacturing processes. This knowledge, along with enabling technologies such as advanced modelling and simulation, improved industrial materials, and advanced sensors and intelligent control systems, can result in major incremental improvements and lead to fundamental breakthroughs. Likewise, developing and demonstrating micro-manufacturing systems (such as mini-mills and micro-chemical reactors) for flexible process configuration can reduce emissions in the long term.

Resource Recovery and Utilisation

Resource recovery and utilisation offer further savings. An advanced concept is an industrial ecology, in which a community of producers and consumers performs in a closed system. Fossil energy is conserved or energy is obtained from sources that do not give rise to greenhouse gas emissions; materials are used or recycled. Through technological advances, the raw materials and resources needed for manufacturing can be obtained by designing products for ease of disassembly and reuse, using more recycled materials in finished goods, and selecting raw materials to eliminate waste discharge or undesirable by-products. Examples of developments that could facilitate this approach are new polymers, composites, and fibres and advanced ceramics engineering techniques. Another approach is to substitute materials such as biomass feedstocks for producing chemicals. Some longer-term technological approaches could use CO_2 as a feedstock and reductants that do not lead to greenhouse gas emissions as substitutes for carbon. These approaches represent fundamental changes in the way raw materials are obtained, the properties they exhibit and the way they are used in the design process (IEA 2000).

Recovery of materials for recycling into new products can contribute to a reduction in greenhouse gas emissions by the energy savings involved in using used materials instead of virgin materials. The major materials that can be recycled include metals, paper, high density polyethylene, milk cartons and glass bottles. Whilst recycling can reduce emissions of greenhouse gases, there are costs involved, and further analysis is needed before general conclusions can be drawn.

Industry-Specific Technology

Ferrous Metals

Several new steel making technologies are emerging and are likely to be adopted widely by the industry because they will lead to substantial overall cost reductions. The new technologies will eliminate a number of existing process stages from conventional steel making and, in doing so, will reduce energy costs and lower energy intensity. It is expected that as existing plants reach the end of their natural life they will be replaced by new technology. In addition to the new production and process technologies, there are options to recover the heat and gas losses in the production process.

Energy saving options in the manufacture of ferrous metals that could become important are:

- Coke dry quenching. Heat losses in coke-making are recovered to generate electricity.
- Pulverised coal injection (PCI) in blast furnaces. This is a technology for injecting coal directly into the blast furnace to reduce coke requirements that has become more widespread since the late 1980s. One tonne of PCI coal used for steel production displaces about 1.4 tonne of coal.
- Top gas recovery turbines (TRT). The recovery of the top gas from blast furnaces to generate electricity.
- Basic oxygen furnace (BOF) gas/steam recovery systems. These recover the gas and steam from BOF and realise a net negative energy use in BOF steel making process.

Emerging production technologies in ferrous metals that could reduce GHG emissions substantially include:

1. Direct reduction iron-making process. DRI involves directly reducing iron ores to metallic iron without the need for smelting raw materials in a blast furnace (which is the most energy-intensive process in iron production). In this process, reformed natural gas is used to convert iron ore into partially metallised iron granules. Some DRI processes require the granules to be compressed into small briquettes (hot briquetted iron) for use in electric arc or blast furnaces.
2. Thin slab and strip casting. These forms of casting replace the conventional hot rolling mill, thereby bypassing the reheating and roughing steps in the normal hot rolling mill production sequence. This produces a thin slab at lower cost with maximal use of the thermal energy of molten iron, while also minimising additional fuel and electricity use downstream.
3. Smelting reduction iron making. The smelting reduction process eliminates both the coke oven and the sinter plant, and allows the use of cheap non-coking coals, thus reducing both operational and capital costs of iron making.
4. Advanced and high efficiency electricity generation technology. High efficiency electricity generation can be applied in the iron and steel industry, facilitating self-generation of some electricity needs. Combined cycle gas turbine (CCGT) is one of the promising technologies (Turton et al. 2002).

Aluminium

Alumina refining and aluminium production are energy intensive processes. Major improvements in energy efficiency can be achieved by:

- minimising heat losses in the digester process; and

- replacing rotary kilns with gas suspension calciners, which will improve energy efficiency and also recover heat for use in other processes.

Remelting aluminium for casting is also relatively energy intensive. Improving energy efficiency by recycling waste heat produced in gas-fired processes can be achieved in three basic ways: load recuperation; recuperative burners; and regenerative combustion. All of these methods re-use the waste heat in furnace exhaust gases.

Other emerging technologies that could reduce GHG emissions from the aluminium industry include:

1. Low-energy aluminium production. The CSIRO is investigating a carbothermic process as one alternative to the conventional electrolytic process for smelting aluminium. The carbothermic process would consume at least 10 per cent less energy per tonne of aluminium produced.
2. Advanced forming/Near net shape casting. Near net shape or thin strip casting is a new technology that integrates the casting and hot rolling of aluminium into one process step, thereby reducing the need to reheat the aluminium ingot before rolling it. Instead of casting slabs of a thickness of 120-300 mm, they are cast as thin as 1-10 mm. The technology is expected to improve the quality of the cast aluminium. It is also expected to produce electricity savings of 20kWh/t.
3. Efficient cell retrofit designs. There are a series of retrofit technologies that could significantly improve cell operation and reduce electricity consumption.
4. Improved recycling technologies. Several new technologies have emerged that help to improve the recovery or processing of scrap. Such technologies can reduce energy consumption by between 25 per cent and 41 per cent while increasing the metal recovery yield. Moreover, increased recycling of aluminium reduces the need to smelt alumina (Turton et al. 2002).

Cement

A large proportion of the energy consumed by the cement industry is used to fire clinker kilns and grind clinker and other inputs to create cement. Over 90 per cent of the energy, usually coal or gas, is used to fire kilns to heat limestone in the calcination process. The remaining energy (less than 10 per cent) consumed by the industry is mainly electricity used to operate kilns, clinker grinding plant and other equipment.

Energy efficiency improvement possibilities include:

- conversion from direct firing to indirect firing;
- improved recovery from coolers; and
- installation of rolled presses, vertical mills and high efficiency separators.

The greatest gains are to be had in improved fuel efficiency for the heating of the kiln. Further energy savings can be made by the greater use of extenders (potentially up to

65% of content) such as fly ash, which offers additional environmental benefits because fly ash is currently viewed as a waste product.

Selected production technologies for the future include:

1. Alternative production processes. In general, the dry production process is far more energy efficient than the wet process, and the semi-wet process is somewhat more energy efficient than the semi-dry process. By 2050 it is likely that the cement industry will rely on the dry process.
2. Conversion from dry to multi-stage pre-heater kiln. Introducing four or five stage pre-heating reduces heat losses and sometimes reduces pressure drop in the kiln, with energy savings of around 13 per cent.
3. Conversion from dry to pre-calciner kiln. This technology can increase production capacity and lower specific fuel consumption, with savings of around 12 per cent in energy consumption.
4. Fluidised bed kiln. Replacing rotary kilns with stationary kilns not only leads to lower capital costs, but also reduces fuel consumption and allows use of a wider variety of fuels. Energy use can be cut by 14 per cent.
5. Product change – blended cements. The production of blended cements involves the inter-grinding of clinker with one or more additives (fly ash, pozzolans, blast furnace slag, silica fume or volcanic ash) in various proportions. The use of blended cements is a particularly attractive efficiency option since the inter-grinding of clinker with other additives not only leads to a reduction in energy use in clinker production, but also reduces emissions in calcination.
6. Product change – hydraulic cements. Shifting to production of new hydraulic cements (cements that set and harden under water, similar to Portland cement dramatically reduces carbon emissions, by up to 90 per cent in some cases (Turton et al. 2002).

Pulp and Paper

The pulp and paper industry uses large amounts of thermal energy (in the form of steam) and mechanical energy (converted from electricity). The thermal energy accounts for about 70-80 per cent of the total primary energy use in the industry, and is mainly used in pulping and drying processes. The process steam can be generated from waste raw material, concentrated black liquor from the industry, and coal, oil and gas. Some 40 per cent of the electricity used in an integrated mill is required for paper manufacture.

Selected energy saving options are:

1. Recycling. An increase in the percentage of waste-paper pulp by 10 per cent can save about 6.5 per cent of energy required for the pulping process.
2. Recovery of chemicals. The amount of chemicals recovered in the pulping process has a great effect on the overall specific energy consumption of the industry. The recovery of chemical products by advanced membrane

processes, particularly using mineral membranes and ultrafiltration, can result in higher recovery rates and less pollution.

3. Cogeneration. Biomass is a major energy resource for the industry. Black liquor and solid biomass residues (bark and log fuel) generated at the mill can be used for cogeneration. The industry also has access to residues from pulpwood harvesting, some of which can be removed from the forest on a sustainable basis. All black liquor and most mill residues are used at mill sites to fuel cogeneration systems, providing steam and electricity for on-site uses.

Some emissions-savings options in the pulping stage are:

- alcohol-based solvent pumping; and
- black liquor gasifier and gas turbine generation technology.

Energy efficiency technologies in the paper-making stage are: dry-sheet forming, press drying, condensed belt drying, impulse drying, air impingement drying, steam impingement drying, and airless drying (Turton et al. 2002).

Chemical Industry

The basic chemical industry can be broken down into the following main processes:

- steam cracking for the production of olefins, butadiene and benzene, toluene and xylene;
- separation of products/co-products by distillation, solvent extraction etc.;
- co-product processing, including catalytic dealkylation of toluene and isomerization of xylenes; and
- steam reforming to produce syngas for ammonia and methanol production.

Heat is used in all the above processes, and motive power is normally provided by electricity, often generated on-site. Improvements in energy efficiency can be achieved through:

- product optimisation;
- optimising the efficiency of heat and power supply; and
- reducing the amount of wastes flared.

Selected energy efficient options are:

- Chemical synthesis. Catalysts can lower the energy requirements for chemical reactions, thereby making processes more energy efficient.
- Separation processes. Many chemical feedstocks, such as petroleum, need to be separated into their components to be useful. Likewise, many chemical reactions produce a mixture of products that must then be separated. In chemical manufacturing processes, separations account for 43 per cent of the

energy consumed and up to 70 per cent of the capital costs. A variety of energy-efficient separation technologies are available, including membranes.

- Waste recovery. The recovery and reuse of liquid and solid waste streams can increase the energy efficiency of processes, reduce the use of raw materials and minimise water usage while reducing or eliminating the need to dispose of the waste.
- Materials technology. Using advanced materials for chemical plant hardware can reduce waste, minimise maintenance and save energy.
- Computer technology. Advanced computer programs for modelling chemical behaviour can help optimise chemical processes. Most critical for the chemical industry is better modelling of the performance of fluids, referred to as computational fluid dynamics (Turton et al. 2002).

Timelines for Changes in Industry Technologies

There is a large list of currently available technologies the adoption of which would considerably reduce GHG emissions form industrial processes. These technologies include:

- process integration for heat recovery;
- high-efficiency motors;
- high-efficiency separation systems;
- state-of-the art steel manufacturing;
- current advanced technologies for the manufacture of aluminium;
- energy-efficient cement production; and
- advanced technologies in the production of pulp and paper.

In the longer run, possible technologies for further reducing GHG emissions include:

- advanced process integration;
- ultra-high-efficiency motors;
- advanced end-use electro-technologies;
- the use of superconducting electronics;
- the introduction of low-energy novel manufacturing processes;
- resource recovery and utilisation;
- new production technologies for steel;
- emerging technologies for aluminium production;
- new technologies for the manufacture of cement;
- new developments in the manufacturing of pulp and paper; and
- advanced technologies in the chemicals industry.

In the very long run we should aim for a ZET industrial energy system. This system would encompass two features. Firstly, in industrial process requiring heat and energy, ZET electricity would displace fossil fuels. Secondly, the use of coal, gas or petroleum products in industrial processes would occur only as part of ZET energyplexes[1] in which energy processes, industrial processes and the recovery of carbon dioxide and wastes occur side by side. The refining of petroleum and the production of petrochemicals would take place in such energyplexes. In the loner haul, gas would displace oil as a primary source for basic chemicals and, further out, coal would become the primary source and coal hydrogenation (conducted in the energyplex) would provide an oil feedstock for petrochemicals.

The Technology System in Industrial Processes

As in the previous chapter, the technology system in industrial processes can be analysed in terms of four different transmission mechanisms – diffusion, induced innovation in specific processes, general purpose technologies and complementary innovations in technology and business processes, and public research and development.

The Diffusion of Emission-Reducing Technologies

Inducements to Diffusion

The competitive pressures associated with globalisation are especially strong in manufacturing. The emergence of China as an industrial power has added to these competitive pressures in many industries while offering opportunities for growth in others.

Higher crude oil prices are a spur to utilising new energy-efficient technologies in oil-using industries like chemicals. Higher oil prices have also flowed on to the price of natural gas and, to a lesser extent, coal. This impacts on gas and coal-using industrial processes and the substitution of electricity for direct fuel use. But electricity, too, is affected by rising prices for primary energy sources, so there are a broad range of incentives to adopt new energy-saving technologies.

A third inducement to diffusion of new emission-saving technologies is a bank of suitable new technologies that offer general improvements in productivity along with energy savings. They include:

- process integration;
- high efficiency motors; and
- new technologies in energy-intensive industries such as ferrous metals, aluminium, cement, pulp and paper, and chemicals.

Constraints

In general the whole energy sector, low capital stock turnover is a constraint on the rate of diffusion of new emissions-reducing technologies. Total manufacturing

[1] The concept of the energyplex is discussed in Paper 8.

systems generally have long lives, but individual items of machinery and equipment have relatively short lives compared with other classes of assets. The overall constraints on diffusion of new technologies is probably less than in other sectors.

Induced Innovation in Specific Fields

There are a number of specific inducements to induced innovation in industrial processes. Globalisation and competitive pressures on manufacturing have a direct effect on innovation. Higher energy prices are a stimulus to energy-saving innovations. This is particularly the case for oil-using industries like chemicals, but there is a general stimulus to reducing energy use across industry.

Opportunities to innovation are fed by upstream basic innovations in such areas as:

- process integration – new plant and retrofit design of existing plant;
- new types of energy conversion processes;
- resource recovery and utilisation;
- high-efficiency motors; and
- specific technologies in energy intensive industries (ferrous metals, aluminium, cement, pulp and paper, chemicals).

The constraints on innovation are less important than the inducements. The slow growth of a few industries is a disincentive for investment in new, state-of-the art, plant.

General Purpose Technologies and Complementary Innovations

General Purpose Technologies in Industrial Processes

In the context of industrial processes, six GPTs have been identified:

- information technology;
- microtechnology;
- nanotechnology;
- superconductivity;
- advanced end-use electro-technologies; and
- process integration.

Information technology is widely used in the manufacturing sector. Further major price reductions will further encourage the use of this technology. Future opportunities will occur for the use of information technologies, particularly new software packages in new design technologies, new types of production systems (modelling physical reactions and optimising industrial processes) and advanced process integration.

New materials technology provides industry with many challenges, both in the manufacture of the materials and in the use of the materials in manufacturing plant. There are emerging requirements for new metal alloys, ceramics, composites, surface engineering, and protective coating systems. Appropriate processes have to be designed for the manufacture of these new materials and these processes have to be cost competitive and take into account energy efficiencies. Advanced materials can be incorporated into manufacturing plant and can reduce waste, minimise maintenance and save energy.

Microtechnology will provide advanced sensors and control systems that will contribute to the optimisation of manufacturing processes. Nanotechnology outputs will also provide challenges for manufacturing processes. It is likely, in the long run, to be used in materials technology, MEMS, motors, additives to existing products, electronics, and design technologies.

Superconductivity technology will be utilised in energy transport and storage, frictionless motors, and low energy digital devices. Advanced end-use electro-technologies will have widespread applications in industrial processes in the future.

There are good prospects for advances in process integration. These would include reactor systems, and heat exchange networks. In addition process integration methods can be applied in contexts other than energy efficiency, such as handling waste, hydrogen, water, and raw material usage, all of which indirectly reduce emissions.

Inducements and Constraints

Inducements to the utilisation of GPTs and complementary technological innovation are likely to a rise as a result of lower costs and/or increased applications of GPTs, and higher energy prices.

There are three types of constraints on a GPT-led growth in innovation in industrial processes. First, many GPTs are still costly to adopt in industries, e.g. nanotechnology, superconductivity, some new materials technologies. Second, firms may be held back from such innovation by a lack of appropriate skills in management and among employees. An unwillingness to contemplate major changes in the business associated with such innovations may also inhibit their adoption. Fourth, regulation in product markets and employment markets may inhibit the structural changes that are necessary to adopt these innovations.

Complementary Innovation in Business Processes

Industrial process integration can be regarded as both a GPT and a new management tool for industry. It provides an overarching discipline for incorporating new technologies in an overall production systems and provides solutions for optimising various facets of business processes.

Integrated production systems will become an important facet of industrial organisation in the long run. Combined Heat and Power systems represent the first step in this direction. In the long run, integrated production systems will incorporate energy production, manufacturing processes and waste recovery and utilisation around a zero emissions framework and the principle of a closed-loop system in water use and materials use.

Public Research and Development

The science and technology sector and public research and development can play an important role in providing the feedstock for commercial innovation in industry.

The major topics that would benefit from basic research are:

- materials technology (novel materials for use in manufacturing and for downstream uses – the development of materials, optimising manufacturing);
- nanotechnologies (exploring new technical possibilities, ascertaining uses, examining manufacturing methods);
- superconductivity;
- the chemistry of advanced separation processes;
- advanced resource recovery and utilisation; and
- advanced methods for process integration including complex mathematical models and advanced software development.

Policy Implications

The Use of Specific Policy Instruments

Economic Instruments

Taxes have important roles to play in steering the structure of industry innovation towards emissions reduction and sustainability. The principal limitation of taxes as a policy instrument is related to the possibility of low price elasticities of demand, including cross-elasticities. Low price elasticities imply large tax increases are needed to secure small changes in quantitative outcomes. The issue of demand responses to price signals in energy consumption is discussed in the next sub-section of the chapter.

The first choice of economic instrument in relation to energy matters is the carbon tax. The reasons for this were discussed in Paper 5. Carbon taxes should be applied to the emissions associated with the final consumption of fossil fuels in industry (petroleum products, natural gas and coal), as well as to the earlier stages of energy production (e.g. the generation of electricity, petroleum refining, the production of coke). A comprehensive framework of carbon taxes will provide a broad incentive to technology developments that reduce GHG emissions directly or indirectly associated with industry production. Subsidies may have a role in encouraging innovation.

Regulation

Regulation has a limited role in climate change policies for industrial processes. It would be possible to provide a framework of performance-based regulatory requirements for specific industrial processes, but it would be complex to administer and a clear second-best to the use of market-based instruments. However, the diffusion of new technologies and the level of commercial innovation could be encouraged by the removal of regulatory obstacles (regulation in product markets and labour markets) to changes in business processes.

Science and Technology Policy

In the discussion on the technology system in industry there was discussion of the four transmission mechanisms for new technologies. The fourth transmission mechanism is public research and development. The ways in which public research and development can facilitate commercial innovation in emissions-reducing technologies were identified.

The key objective of policy is to encourage the conduct of such research and the engagement of the private sector in this process. This objective can be attained through the development of an appropriate science and technology policy. This would involve:

- appropriate changes in the volume and quality of basic R&D;
- the evaluation of research projects;
- the involvement of the private sector in cooperative approaches to R&D; and
- ensuring that the science and technology system possesses the capabilities to perform the functions outline above.

Education and Information

Benchmarking Best Practice

International databases are being developed for benchmarking local performance in energy efficiency in the residential, commercial and industrial sectors against available international data. This work is being complemented by analyses, in specific sectors, of the technical and economic options for improvement of local performance against these benchmarks. So far as industrial emissions are concerned, specific policy interventions include: standards and certification for new motor systems; voluntary programs to improve the efficiency of new technologies and to accelerate the deployment of new boilers, machine drives and process-heat equipment; and research and development to improve the efficiency of new equipment entering the market after 2015 (IEA 2004).

Life Cycle Analysis

Life cycle analysis considers the whole product life cycle in assessing energy use. This methodology embraces sourcing of materials, manufactures or construction, product use and product disposal. This analysis attempts to determine cost-effective opportunities for achieving net greenhouse gas emission reductions involving substitution of materials or manufacturing processes, design or product operation considerations, disposal of product (including recycling and recovery of energies), and whole-of-life-cycle approaches that lead to net energy reductions over the whole life cycle of the product.

Education and Training

As in the case of sustainable transportation strategies discussed in Paper 5, there is an important role for education and training to increase the capacity for the development of, and appropriate use of, new technologies. Policies need to focus on the training of managers and employees to achieve such goals.

Conclusions

The IEA Reference Scenario (IEA 2004) provides an indication of trends in industry-related emissions over the period to 2030 under Business-As-Usual assumptions. Over that period, steady improvements in technology enable reductions in the energy intensity of industry and the electrification of many industrial processes.

As to the latter, it should be noted the use of electricity does not give rise to any emissions, so that the substitution of electricity for the direct use of fossil fuels in industrial processes leads to a reduction in GHG emissions at the point of consumption. However, the extra use of electricity by industry gives rise to an increase in electricity generation and, to the extent that this occurs through the use of fossil fuels, extra emissions occur at the point of electricity production.

Table 2 provides a summary of CO_2 emissions from industry over the period 2002 to 2030.

Table 2. Industry and the IEA Reference Scenario

CO_2 Emissions from Industry, Average Annual Rate of Growth	2002/2010	2010/2020	2020/2030	2002/2030*
OECD	0.9	0.6	0.4	13.1
Developing Economies	1.9	1.7	1.5	53.5
World	1.5	1.3	1.1	36.6
Energy Consumption by Industry as a % of Total Final Energy Consumption	**2002**	**2010**	**2020**	**2030**
OECD	29.9	29.4	28.9	28.6
Developing Economies	33.0	32.5	31.9	31.0
World	31.6	31.2	30.7	30.2
Energy Source as a % of Energy Consumption by Industry, World	**2002**	**2010**	**2020**	**2030**
Coal	17.0	15.8	14.2	13.0
Oil	27.0	26.5	26.0	25.5
Gas	23.3	23.9	24.4	24.5
Electricity and Heat	25.4	26.6	27.9	29.2
Renewables	7.2	7.4	7.6	7.8

Note: * percentage increase 2002 to 2030.
Source: Derived from IEA (2004, pp. 430-437, 478-483).

In the OECD, value added by the industrial sectors is expected to increase by around 2.0% a year. However, the projections indicate that energy consumption is likely to grow by 1.0% per year (implying steady increases in energy efficiency) and emissions are projected to grow by 0.6% per annum (as a consequence of electricity displacing oil and coal as a source of direct energy) so that emissions increase by 13.1% over the whole period.

In the developing economies, emissions from industry are projected to rise by 53.5%. This marked growth in emissions is based on several features of the development of these economies:

- the particularly rapid growth of several leading economies (China, India, and several Southeast Asian economies);
- a process of industrialisation that is still increasing in many developing economies, in contrast to the advanced economies of the OECD; and
- lags in the adoption of energy-efficient technologies and the rate of electrification when compared with the OECD.

In Table 3, data from the Optimistic Scenario for advanced economies compiled in CSES (2004) indicates the substantial gains that could be made by developing and adopting emissions-reducing technologies at an accelerated rate.

Table 3. Optimistic Scenario for the Advanced Economies

3a. Average Annual Rate of Growth of GHG Emissions from Industry

2000/2010	-0.4
2010/2020	-0.2
2020/2030	-1.3
2030/2040	-3.4
2040/2050	-3.8
2000/2050	**-60.7**

3b. Contributions to the Trends in GHG Emissions from Industry, 2050

	Index	% change 2000/2050
Zero Improvements in Industry Sustainability	100.0	133.6
Increases in Energy Efficiency	68.8	60.9
Changes in Energy Source	24.4	-42.9
Combined Effects of Previous Two Effects	16.8	-60.7

Source: Based on CSES (2004, pp. 65-66).

Table 3a indicates that GHG emissions for industry in the advanced economies decrease marginally up to 2020 and then decline at an accelerating rate over the following thirty years.

Table 3b and associated information from CSES (2004) indicates:

- industrial production in the advanced economies increases by 170% between 2000 and 2050;
- in the absences of changes in energy efficiency or energy sources, GHG emissions from the use of energy by industry would increase by 133.6%, the rate of growth being held back by the fact that the most energy-intensive industries are, on the whole, relatively slow growing when compared with the more rapidly growing industries;
- increases in energy efficiency made possible by a range of general and industry-specific technologies would reduce the growth of GHG emissions to 60.9%;

- changes in the energy sources of industrial processes (the substitution of electricity for fossil fuels) would, by itself, reduce emissions to 2050 by 42.9%; and[2]
- the combined impact of the past two influences would reduce GHG emissions by 60.7%.

3. Energy Consumption Associated with Building Use

Buildings Technology

Overview

GHG emissions from building use in the advanced economies were 1463 Tg (CO_2–e) in 2000. Some 64% of these emissions came from energy consumption in residential buildings. Most of the reminder came from commercial building use (CSES 2004). The major sources of residential energy consumption in the six major advanced economies were space heating (55%), water heating (19%) and appliances (19%). In the commercial sector, lighting, office equipment and air conditioning are more important source of energy consumption than is the case for residential buildings.

Value added in the services sector in the advanced economies is expected to rise at a slightly faster rate than for GDP as a whole. On the other hand, rising productivity in the services sector can be expected to boost services value added per services floor area to a moderate extent, implying a slower rate of growth for the services floor area than for services value added. An increase in the energy efficiency of buildings used by the services sector and also by equipment used by the sector are also expected to limit the growth in services energy consumption, but it will still amount to 58.4% between 2000 and 2030 in the advanced economies. The shift between energy sources, with electricity displacing petroleum products, reduces the average emissions intensity of the sector by a sizeable amount, thereby constraining the overall rise in GHG emissions. Nevertheless, this still amounts to 30.8% between 2000 and 2030 (CSES 2004).

Energy consumption by the residential sector in the advanced economies is expected to grow as a result of increased population (a relatively modest influence), higher per capita incomes to households leading to increased ownership of energy-using equipment in residences (particularly computer and home entertainment equipment) and an increased task for household equipment in such areas as heating and cooling as a result of increased dwelling space. However, the overall rate of growth of residential energy consumption will be significantly constrained as a result of further increases in the average energy efficiency of household heating (associated in part with improved housing design including insulation), lighting and appliances (particularly through the operation of current energy labelling and standards). The major change in residential energy sources is a switch away from the consumption of petroleum products towards

[2] In the short run, electrification would add to emissions to the extent that electricity is generated from fossil fuels. However, in the long run alternative energy sources would supply the majority of electricity generated under the Optimistic Scenario.

electricity. The use of biomass (wood) as a residential energy source will be of declining importance. With respect to other renewables, solar heat is expected to increase in relative importance. Geothermal energy will also increase in importance (CSES 2004).

Improvements to the design of commercial and residential buildings have the potential to make an important contribution to limiting greenhouse gas emissions. Building design has to be considered in its broadest sense – relating both to the architectural design of the building itself and to the wider building envelope and aspects of subdivision design which impact on energy efficiency.

Building stock turns over only very slowly, but the equipment used in residential and commercial buildings has a much shorter lifetime. There is a significant opportunity to replace it with more efficient equipment and systems by 2010 and shortly beyond. Building retrofits also provide opportunity to improve building shell components such as windows and insulation.

Building Systems[3]

Building Design and Retrofit

Energy use can be effectively reduced in commercial buildings through improvements in building design and construction, including walls, roofs, foundations, glazing and solar control. The energy efficiency of the commercial building shell can be increased by 45 per cent on average through improvements in design and construction compared to the existing buildings.

Large reductions in residential energy use can be achieved through improved building design, including correct building orientation and shading, appropriate placement of windows and the use of sunshine for lighting and heating, a high level of insulation on exterior surfaces and heat recovery systems. In Australia, a shift to an efficiency of 5 stars under the Nationwide House Energy Rating System for all new dwellings from 2000, in combination with aggressive promotion of adding ceiling insulation to the existing building stock, is projected to save 18.4 per cent of residential heating and cooling GHG emissions by 2010. For new dwellings alone the increased efficiency is in the range 50 to 55 per cent (Turton et al. 2002).

The retrofit of both commercial and residential buildings offers scope for the achievement of increased energy efficiency and is a means of countering the otherwise efficiency-retarding impact of slow capital stock turnover[4]. The IEA Implementing Agreement on Energy Conservation in Building and Community Systems (ECBCS) has undertaken assessments on the potential of retrofit measures in government and education buildings.

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[3] Note IEA (2000ETCC).

[4] New buildings amount to only 2 to 3 per cent of existing building stock in any given year (Brown et al. 2005).

Energy Management Systems

Building energy management and control systems are promising technologies for near-term emissions reduction. Such systems automatically regulate the operation of temperature control, lighting and other systems in buildings. These systems range from simple point-of-use timers to complex microprocessor-based systems that can minimise unnecessary equipment operation and fulfil other functions such as economiser cycling or varying supply air or water temperatures.

Some systems, such as timer-controlled water heaters, are relatively simple and have been in use for many years. Others are highly complex and can produce levels of automation that make possible significant energy savings. The technology is commercially available.

Computerised energy management systems typically provide a 10 per cent to 20 per cent energy savings, although savings of 30 per cent or more are possible in existing commercial buildings, even in many thought to be working properly now. There are also system benefits; energy management systems that turn off lights in unoccupied places can reduce the lighting heat load, and thus the need for air conditioning. In addition, energy management systems could be more effective when used in conjunction with energy-storage and waste-heat-reclamation systems.

A future sustainable building can be envisioned that would have a minimal impact on the indoor, local, regional and global environment. It would use recyclable materials, would consume a minimum of non-renewable heat and electricity, and would employ heat recovery and heat cascading. It would be connected to wastewater cleaning/recycling and to waste management/recycling, would have high energy efficiency, and would provide good thermal comfort, indoor air quality and lighting throughout the year.

With respect to certain types of non-dwelling buildings, particularly offices and shopping centres, strategic facilities planning (SFP) is an important driver of change. SFP is an advanced technique for property management which marries the specification of corporate goals to the technological building requirements that meet these goals. It is a process not just for building users but building owners and developers as well. It is a reaction against the prevailing under-management of property assets in the corporate sector. It will progressively lead to greater efficiency in the design of buildings, and greater pressure to upgrade or scrap existing buildings (IEA 2000).

Specific Technologies[5]

Distributed Energy

Distributed energy resources are small power generation or storage systems located close to the point of use. Not all distributed energy is climate-friendly, a case in point being diesel-generator sets. However, distributed generation technologies like photovoltaics and fuel cells have zero or low emissions intensities. Today’s distributed generation market is largely limited to backup generation. Customers

[5] Basic references are IEA (2005a), IEA (2005b) and Brown et al. (2005).

include hospitals, industrial plants, Internet server hubs, and other businesses that have high costs associated with power outages. However, future buildings can be completely self-powered through the use of fuel cells, small turbines, photovoltaic building components (panels, shingles, etc.) and energy storage systems. Excess electricity can be generated for sale to the grid.

Using distributed generation technologies, particularly cogeneration, can improve the efficiency of energy supply in commercial buildings. Distributed generation has the advantage that electricity transmission and distribution losses are largely eliminated. Commercial buildings often have a suitable balance of energy demands – electricity is needed for operating office equipment, lighting and ventilation pumps, compressors and motors, while waste heat from cogeneration can be used for space and water heating and, in some cases, cooling.

Energy storage is an important aspect of residential cogeneration systems. Research and development is occurring in relation to two particular energy storage technologies.

The first technology is Underground Thermal Energy Storage (UTES). Groundwater and the subsoil represent a substantial natural, low-temperature thermal store that can be used for the cooling or heating of buildings. The cold can be extracted from the ground via wells, ducts, energy pillars and other means and used either directly, or indirectly using heat pumps. UTES has been extensively investigated in several IEA-commissioned studies. Many large-scale pilot and demonstration plants have shown the technical feasibility and economical advantages of UTES. As a result, implementation has been growing in a number of Northern European countries.

Another new and innovative thermal energy storage concept is based on the use of phase change materials (PCM) and thermo-chemical reactions. A phase change occurs when, as a result of heating or cooling, an element changes between the liquid, solid or gaseous states. PCM are often paraffin wax or salt hydrates, and are commonly used as hot or cold gel packs (for transporting medication, laptop coolers, warm pizza boxes, etc.). Comprehensive R&D has been carried out under the IEA study 'Advanced Thermal Energy Storage through Application of Phase Change Materials and Thermo-chemical Reactions. Since this study was launched, considerable progress has been made on the feasibility of the concept and first steps towards market deployment.

Incorporation of micro-encapsulated PCM (in the form of paraffin wax) into the gypsum walls or plaster increases the thermal mass and capacity of lightweight buildings. By night the PCM in the microcapsules cools and solidifies. During the day the warm air mixes with the cool walls, reducing the daily temperature swing by several degrees, and thereby avoiding the need for electric chillers or, at a minimum, reducing the cooling requirements. Another application of active cooling systems is macro-encapsulated salts that melt at an appropriate temperature. The PCM is stored in a building's air vent duct and the cold air is delivered through large-area ceiling and floor systems.

Other thermo-chemical reactions like adsorption[6] of water vapour to silica-gel or zeolites[7] can be used to generate heat and cold as well as regulate humidity. Of special importance in hot, humid climates or confined spaces where humidity levels are high, these open sorption systems use lithium chloride to cool water and zeolites to absorb ambient humidity.

Heating and Cooling

Efficient heating, ventilation and air-conditioning equipment can be based on the use of heat pumps or condensing gas furnaces.

A **heat pump** absorbs heat at a low temperature from an external heat source (or from internal exhaust air) and delivers it at a higher temperature to the heating system of a building. Alternatively, it may function as a space-cooling unit, absorbing heat and rejecting it outside the building. Heat pumps may be classified as air- water- or ground-source, depending on the external heat source, and may transfer heat to internal air or water. The vast majority of heat pumps operate on the vapour compression cycle, driven by an electric motor. A growing minority is driven by an internal combustion engine or employs the absorption principle and uses gas or waste heat as the driving energy. Electric heat pumps typically consume about one-fourth to one-half as much electricity for heating as electric resistance-based systems. They can reduce energy consumption for heating by as much as 50 per cent compared with fossil-fuel-fired boilers, and further improvements are possible.

Efficient electric heat pumps are on the market today, as are high efficiency gas-fired absorption heat pumps and condensing gas furnaces. Heat pumps are also available for applications other than space heating and cooling. For example, state-of-the-art electric heat pump water heaters, which extract heat from ambient air, exhaust air, or circulating water and transfer it to water in the storage tank, have unit energy consumption as much as 70 per cent lower than the average water heater stock. But they are up to five times more expensive than electric resistance water heaters. Heat pumps still have significant potential for improvement.

Condensing gas furnaces are a second advanced technology for heating and cooling. Gas-fired furnaces incorporating ‘condensing’ technology use a secondary heat exchanger to recover the latent heat of water in the combustion exhaust gases. Condensing releases an additional 10 per cent to 20 per cent of the heat available in the products of combustion, enabling condensing gas furnaces to achieve efficiencies of 90 to 97 per cent. Condensing technology can also be used in integrated space and water heaters with dramatic efficiency gains. Efficiency improvements in condensing gas furnaces are limited by the higher heating value of gas.

Proper **insulation** reduces heat loss in cold weather, keeps excess heat out in hot weather and generally helps maintain a comfortable indoor environment. Traditionally, insulation has consisted of lightweight fibrous or cellular materials with pockets of air or gas, such as glass fibre, mineral wool and expanded plastics. Recent innovations have occurred in transparent and dynamic insulation materials and in phase-change and crystal structure-change materials that can be used indoors for

[6] The adhesion of a substance to the surface of another solid or liquid.
[7] Naturally occurring micro-porous crystalline solids made of aluminium, silicon and oxygen.

passive solar storage. Building-insulation performance has improved by a factor of two to three over the past 25 years. Super-insulations that perform at leat three times as well as today's technology will soon be available for niche markets – vacuum-powder-filled, gas-filled and vacuum-fibre-filled panels; structurally-reinforced beaded vacuum panels; and switchable evacuated panels with insulating values of more than four times those of the best currently available materials.

New reflective **roof** products are in development. New pigments reflect most of the incident thermal energy. Research is under way to develop smart roofing materials that absorb solar energy when the outdoor temperature is cool and reflect solar energy when the outdoor temperature is warm. Because roof surfaces are replaced in regular, albeit fairly long, intervals, these technology opportunities are pertinent for both new and existing buildings.

Wall systems include framing elements and insulated cavities. New wall designs minimise heat loss by as much as 50% by reducing the amount of framing used and by optimising the use of insulated materials. In existing buildings, opportunities for retrofits incorporating the latest technologies are eliminated by the need for modifications to window jambs and doorframes. However, coatings under development for roofs could become a constituent of siding materials. Another approach is to take advantage of new insulating fabrics that could be hung from or applied to interior wall surfaces. The reflective properties of such materials can also be engineered to provide greater human comfort at reduced or elevated indoor temperatures, further increasing energy savings.

Windows can strongly influence a building's overall energy performance. Low-emissivity coatings reduce the transfer of heat radiation from the inside of the building to the outside. Gas-fill windows, in which the gap between multiple glazing layers is filled with low-conductivity gas, also reduce heat loss. There have been spectacular improvements in window thermal resistance. Low-emissivity coatings and gas-fill window technologies are technologically mature. Other advanced technologies are now commercially available, such as windows with selective coatings that reduce infrared transmittance without reducing visible transmittance. The best windows on the market insulate three times as well as their double-glazed predecessors.

Window and insulation retrofits could reduce building-related emissions significantly, particularly in parts of Europe where many homes are poorly insulated. There are opportunities in North America as well, where 20 per cent of residences are poorly insulated. Approximately 40 per cent of new window sales in the United States are of advanced types (low emissivity and gas-filled). In the United States, an estimated 20 per cent of residential heating and cooling energy use is associated with losses through windows. A complete change of the stock to the most cost-effective, energy-saving window systems could reduce energy losses through windows by two-thirds.

System-level benefits result from interactions among technologies. Better windows and insulation reduce the need for heating and cooling. In new homes, the savings can be more dramatic, as when passive solar design can be used and energy-producing and energy-using equipment can be optimised for the entire building.

Cooling costs can also be reduced by reflective roofing and the strategic positioning of trees. Sensor-controlled ventilation systems with air filtration and heat exchange are another area of innovation.

Systems for heating or cooling communities – **district heating and cooling** (DH&C) systems, also referred to as community energy systems – are promising for near-term emissions reduction. These systems are used primarily for heating buildings in the winter, but are also used to provide air conditioning year-round. District heating systems transport heat, in the form of hot water or steam, from a central plant to buildings via an underground, insulate pipeline. The network can range in length from several hundred metres to many kilometres. DH&C systems can use a wide variety of energy sources, including industrial waste heat and condenser heat from numerous types of thermal power generation. These systems are used across Europe, North America and Japan, but primarily in Northern, Central and Eastern Europe. In Finland and Denmark, for example, district heating systems account for 50 per cent of the space-heating market. DH&C systems have enormous potential for China.

The technology is fairly well developed, although there is considerable potential for improved technical efficiency and reduced costs. Technical efficiency improvements are possible through better insulation of the pipes that carry heat to and among buildings, improved methods for operation and status control, and methods fro remote supervision of consumer installations. Harmonised design and installation methods for distribution systems are also needed.

The potential energy savings are high in individual applications, both new and retrofit. Savings are greatest when district systems make use of waste heat from thermal power generation. Prospects for growth are good in several European countries, such as the Netherlands and Austria. The potential in North America may be increasing as interest in independent power production grows, leading to new gas-fired community cogeneration (CHP systems).

Using more efficient heating equipment in **commercial buildings**, such as improved heat pumps for space heating, could provide at least three times as much heat as an electric resistance heater. Various heat pump technologies can be used, including electric, ground-source and natural gas. In general, energy efficiency of space heating can be improved by 60 per cent. Heat pump technologies can also be applied to water heating, with consequent savings in energy used of 50 per cent.

Using more efficient cooling equipment in the air-conditioning installations of commercial buildings can raise the efficiency of energy utilisation by 64 per cent. However, the most efficient way to cool large commercial operations may well be with absorption chillers powered by waste heat from cogeneration or solar heat. In addition, between now and 2050 similar improvements in chiller and air system design are expected to deliver an improvement in efficiency similar to that anticipated for air-conditioners (64 per cent).

Heating, ventilation and cooling control systems have the potential to achieve large energy efficiency improvements for commercial buildings by optimising the operation of equipment throughout the year. By combining control systems with high efficiency motors ad variable speed equipment, the efficiency of building ventilation systems can be improved by around 72 per cent.

Installing more efficient equipment can reduce emissions from space heating and cooling in **residential buildings**. For example, a 6-star-rated gas heater will reduce emissions by 45 per cent relative to the 1-star equivalent. Similar savings are available in air conditioners in both heating and cooling modes and further savings are quite feasible. For example, in the United States it has been estimated that using high efficiency air-conditioners with larger condenser and evaporator areas and more efficient fan motors ad compressors can raise energy efficiency by around 64 per cent. Improved control and management systems (such as timers, occupancy sensors and zoning) can further reduce energy used in space heating and cooling. In addition, residential distributed generation technologies such as fuel cell or micro-turbine cogeneration can be used for space heating (and cooling with absorption chillers) while supplying electricity for other residential energy requirements.

Fuel-mix changes are an important issue with respect to space heating. In this respect, improved building insulation is the single most important factor for immediate emissions reductions. This, and high-efficiency heating technology, could lead to substantial emissions reductions as well as lower heating bills. Likewise, the combination of hydroelectricity and electrolytic hydrogen could generate net savings if used in super-insulated residences. Photovoltaic hydrogen in conjunction with super-insulation can achieve zero carbon emissions at significant cost at present. Commercial heating follows the trend of residential heating. Here, the cogeneration of electricity and space/process heat production is an essential prerequisite.

Hot Water

Major savings are also possible in water heating. The available technologies for water heating include high efficiency gas, heat pump and solar water heaters, and major savings are possible compared to conventional systems. However, considerable scope exists to replace nearly all electric resistance water heating systems with solar thermal systems boosted with either high efficiency gas combustion or heat from residential cogeneration systems. Water efficiency improvements, achieved with flow control fixtures, can also achieve substantial reductions in energy consumption.

Refrigeration

Supermarkets use large amounts of refrigeration equipment, both to cool space and to store food. The IEA study – advanced supermarket refrigeration and heat recovery systems – analysed the impact of energy use in supermarkets on global warming. The results of the study demonstrated that energy savings of more than 10% can be achieved and reductions in global warming of up to 60% are possible with low-charge refrigeration systems (compared to traditional designs).

Lighting

Of the total electricity consumption in buildings, lighting consumption ranges from 5 to 15 per cent in industrialised countries, and up to 86% in developing countries. Several components affect lighting energy use, including lighting equipment, performance targets and design, and control and integration. Efficient lighting technologies offer the potential for near-term emissions reduction. State-of-the-art technology includes electronic ballasts and compact fluorescent lamps (CFLs), high-efficiency sodium discharge lamps, lamp-based torchieres (up-lights) to replace halogen torchieres, and measures to increase lighting-system efficiency.

Electronic ballasts and CFLs are established technology. Several high-intensity discharge lamps are available, although smaller and low-wattage lamps are being developed. Sulphur lamps have recently been developed that can replace conventional high-intensity discharge lamps in many commercial applications. A CFL-based replacement for inefficient, high-temperature halogen torchieres has recently been developed that uses 75 per cent less power, lasts longer and eliminates fire hazard. Measures to increase the efficiency of lighting systems – controls and dimmable ballasts, time-based and occupancy- or daylight-linked controls, and efficient ballasts – are commercially available.

Efficient lighting technology can significantly reduce energy use. Moreover, unlike other parts of the building infrastructure, most lighting system components are replaced relatively quickly (within 10 years) and thus provide opportunities to introduce more efficient technologies on a regular basis. For example, a U.S. study projects that with development and intelligent use of more efficient lighting technologies and design, lighting energy use could be reduced by more than 50 per cent by 2020, with equal or improved health, comfort and productivity.

Another advanced technology aimed at providing energy efficient lighting is that of tracking daylight collectors (including super-windows optimised for orientation to take advantage of natural lighting) connected to ‘piped’ light-distribution systems. Natural and electric lighting systems can be integrated through the use of sensors and controls.

The amount of energy used for artificial lighting in commercial buildings can be reduced by using efficient compact fluorescent lights, installing day-lighting control systems to allow perimeter lighting to be switched off when daylight is sufficient, and optimising the integration of lighting components and systems into the total building system. In addition, the installation of high frequency ballasts instead of core-coil ballasts and the addition of reflectors or high efficiency luminaries to standard fluorescent light fittings can greatly reduce energy use. These various measures can increase energy efficiency in commercial building lighting by 70 per cent. Since artificial lighting systems generate substantial heat, improvements in efficiency will also reduce space cooling energy requirements.

In the case of residential lighting, efficient house design will allow natural light to be used at maximum level without creating major heating gain or loss pathways. Efficient artificial lighting technologies similar to those discussed for the commercial sector are also available, although it is assumed unlikely that household consumers will accept lighting control systems and a significantly increased penetration of fluorescent lights (except for compact fluorescent bulbs). Increases in bulb output intensity are also less likely to produce as large a reduction in residential lighting energy use, because of the layout of residential buildings.

Appliances and Equipment

More efficient **electric stoves** (electric induction cook-tops) incorporating reflective pans under elements and reduced electric resistance use less energy compared to conventional electric elements (resistance) or gas elements. Another option is to use gas cooking with improved combustion efficiency. As is the case for any appliance that can operate on electricity or gas, the source and generation efficiency of the electricity has a large bearing on relative greenhouse gas emissions.

Further improvements in energy efficiency can be expected over the broad range of domestic appliances.

The energy efficiency of **office equipment**, such as computers, printers, photocopiers and vending machines, will improve through the natural turnover and replacement of old equipment. Some new equipment is significantly more energy efficient. For example, the use of liquid crystal technology instead of cathode ray tubes in visual display units (VDUs) leads to improvements in energy efficiency of 60 per cent or more. Changes in computer technology and the move towards portable equipment will also reduce the electricity intensity of office equipment; on average, a 45 per cent gain in energy efficiency can be readily achieved. Increased use of microwave ovens in place of electric resistance, gas heating in stoves and ovens, and increasing the thermal efficiency of gas stoves and ovens can, on average, raise energy efficiency by 40 per cent.

Electricity leakage can give rise to significant greenhouse gas emissions, depending on how the electricity is produced. Home and office appliances and equipment continue to use electricity while in stand-by mode or turned off. These electricity losses can amount to as much as 10 per cent of residential electricity use in the advanced economies. Significant electricity waste also occurs in the commercial sector. Taking all sectors into account, such leakage amounts to about 1 per cent of emissions. Technologies are available to reduce such electricity leakages.

Technologies are available today that, when installed in equipment at the time of manufacture, can limit electricity leakage to one watt for a wide range of electronic devices. Technologies are also available today to retrofit many categories of appliances and equipment (computers, fax machines, photocopiers, printers and televisions) to reduce electricity losses.

Savings of 75 per cent of current electricity leakage losses are technically feasible and cost-effective for new equipment, with no sacrifice of consumer features.

Electricity demand associated with **standby power** is a major issue for future energy consumption in the residential and services sectors. Standby power is the electricity consumed by end-use electrical equipment when it is switched off or not performing its main function. The most common users of standby power are televisions and video equipment with remote controls, electrical equipment with external low-voltage power supplies (e.g. cordless telephones), office equipment and devices with continuous digital displays (e.g. microwave ovens). The actual power-draw in standby mode is small, typically 0.5-3.0 watts. However, standby power is consumed 24 hours per day, and more and more new appliances have features that consume standby power. Total standby power is now approaching that of refrigeration.

Electricity consumption in standby modes is often far higher than necessary. For some products, existing engineering practices could greatly reduce standby power use at relatively low cost and without affecting how the product operates or consumer satisfaction. More widespread use of existing power management technology could reduce total standby energy consumption by as much as 75% in some appliances.

The Timelines for New Buildings Technology

Near Term Technologies

There are a considerable number of near term emissions-reducing technologies that could be speedily adopted by the buildings sector. They include:

- building design and retrofit;
- building energy management systems;
- advanced heating and cooling systems;
- low-emissions hot water systems;
- advanced refrigeration systems;
- high-technology lighting; and
- energy efficient appliances and equipment.

Medium Term Technologies

Current R&D is providing prospects for a significant number of new technologies that are capable of reducing medium-term GHG emissions in the building sector. Examples include:

- distributed energy systems;
- new types of building insulation;
- advanced technologies for windows;
- reflective roofing;
- advanced lighting systems; and
- further advances in the energy efficiency of appliances and equipment.

Zero Emissions Buildings Technologies

A ZET system for buildings would eliminate the consumption of fossil fuels, which give rise to carbon dioxide emissions that would be uneconomic to capture. Thus coal use (for heating), petroleum products (heating and auxiliary motors), and gas (heating and cooling) would eventually be phased out.

Buildings would become all-electric in terms of energy consumption. The use ZET electricity would extend to:

- heating and cooling via heat pumps and absorption chillers;
- all forms of cooking; and
- auxiliary motors.

Distributed energy systems utilising photovoltaic cells and fuel cells would power buildings. Cogeneration systems would link building energy systems with electricity grids.

The Technology System in Building Use

The Diffusion of Emission-Reducing Technologies

Based on current practices in building use, most owners and occupants could significantly improve the energy efficiency of their buildings. The list of near-term technologies presented above and the analysis of Brown et al. (2005, pp. 14-16) confirm this.

Inducements

There are three major inducements to the diffusion of emission-reducing technologies in buildings - increased primary energy prices, general competitive pressures, and the bank of suitable technologies that can be diffused.

Increased primary energy prices are an inducement to technology diffusion. In the context of buildings, oil prices are less important than gas and electricity prices, the latter being affected by increased costs of natural gas and coal. Buildings in the residential sector are less affected than commercial buildings.

As globalisation begins to develop in many services industries, competitive pressures to take advantage of new commercial technologies increase.

There is a large bank of suitable technologies for adoption in building design and equipment used in buildings. They include:

- building design and retrofit technologies;
- building energy management systems;
- district heating and cooling systems;
- advanced heating and cooling equipment;
- hot water systems;
- advanced refrigeration equipment;
- advanced lighting equipment; and
- more energy efficient domestic appliances and office equipment.

Constraints

An important constraint that operates in residential building use and also, to some extent, commercial building use, is that of information barriers. Opportunities to absorb innovations in building use of building design are foregone because of lack of information on the long-term benefits of the technologies, or a disjunction between the owners of the buildings and the users of the buildings.

Low rates of capital stock turnover apply generally to buildings, thereby inhibiting the diffusion of innovative new building designs. However, building retrofit is widespread and can incorporate many of the new technologies – although retrofit is a medium-term option usually rather than a short-term option. Moreover, the turnover of office equipment and household appliances is relatively quick.

Cost barriers inhibit the adoption of some prospective technologies.

Induced Innovation in Specific Fields

There are a number of inducements to innovation in specific fields. Strong demand growth exogenous of energy developments will encourage innovations. The service sector is generally a high growth sector which impacts on building use. Residential requirements are growing as housing standards rise in both advanced and in major developing economies. Higher energy prices provide incentives for energy-saving innovations.

There is also the inducement of a large bank of innovation opportunities. Examples include:

- building design and retrofit;
- energy management systems;
- distributed energy;
- advanced heating and cooling systems;
- new types of insulation and windows;
- advanced refrigeration;
- advanced lighting; and
- increased energy efficiency in domestic appliances and household equipment.

General Purpose Technologies and Complementary Innovations

General Purpose Technologies and the Building Sector

Building design and building use can be affected by five GPTs: information technology, microtechnology, materials technology, distributed energy, and nanotechnology.

Information technology has an important role to play in the development of advanced energy management systems, as does microtechnology in the form of sensors and controls. Examples of advanced materials technology relevant to the building sector are high-technology insulating glass, other insulation materials, building cladding, roofing materials, and structural materials. Distributed energy systems can provide cogeneration systems for buildings by using fuel cells, solar cells incorporated into the building design and materials, and advanced energy storage technologies.

Nanotechnology has widespread uses in advanced building systems:

- *High-tech coating materials*. The use of carbon nanotube filled conductive composites in construction and manufacturing coatings.[8]
- Nanotechnology-based home and office lighting using light conducting polymers.
- *MEMS* implanted in structural building materials, and ultra-strong lightweight materials for special applications. Improved insulation qualities.
- *Glazing* – controlling the optical properties of glass to pass only desired frequencies of light, and blocking damaging infra red and ultra violet frequencies. Self-cleaning glazing.
- *Energy*. Advanced solar energy systems to improve the energy efficiency and environmental impact of the built environment.
- *Advanced Virtual Reality design technologies.* These technologies will increase the speed and reduce the cost of building design.

Inducements and Constraints

The inducements to GPT-led innovation are higher energy prices, strong demand for new buildings, advances in the cost-competitiveness and applications of GPTs.

The major constraints would be the cost of many of these technologies, the adjustment costs to industries of applying these technologies, information barriers to the demand for the technologies, and prescriptive building regulations.

Complementary Innovation in Business Processes

Complementary innovation in business processes may be required to make full use of GPTs and complementary technological innovations. These business innovations can be considered with respect to the building envelope, commercial building usage, and residential building usage.

In many parts of the world building constructions systems are increasingly flexible and capable of absorbing new technologies and adapting construction methods and systems. In some places, regulatory barriers may inhibit the development of such flexibility.

The flexibility of commercial building usage to innovative changes like advanced energy management systems will vary form industry-to-industry. By and large, those industries most open to some form of international competition will be the most capable of responding to new innovations. Retail and wholesale trade would top the list, but rigidities are found even in this industry in such regions as Western Europe

[8] Coating technology is now being strongly influenced by nanotechnology. Note nanocrystalline powders, used for example to in coatings sprayed on metallic stainless steel and tungsten carbide to increase strength and hardness.

and Japan. The least adaptable industries are likely to be education, health and entertainment, with banking, finance and insurance in between.

Residential building use in the advanced and middle income economies responds fairly promptly to innovative new items of individual equipment where they are strongly marketed. The speed with which households respond to more complex innovations like household energy management systems remains to be seen.

Public Research and Development

Public research and development may be of assistance to longer-run trends in building-related innovation in distributed energy systems, heating and cooling systems, and lighting systems.

Policy Implications

Addressing the Barriers to Technology Development

Climate change policies as they apply to industrial processes need to address the barriers to innovation in, and the diffusion of, new emissions-reducing technologies. There are five significant barriers to technology development in the buildings sector.

The first of these barriers relates to the disjunction between owners of buildings and tenants. Where the original owners of a building are responsible for decisions made about the technologies incorporated into the building design and the equipment installed in buildings, tenants generally pay for the energy consumed in building use. The owner has little incentive to take into account energy matters in building technologies, while the tenants have limited options for energy management. The solution to this problem lies in information and awareness programs. Such programs would provide tenants with information about the costs of energy options in the long run, which could then be taken into account when making decisions about which buildings to choose for tenancy. If tenants are fully informed, they should be more willing to pay higher rentals for energy efficient buildings, thereby encouraging owners to take energy considerations into account in building design and fit-out.[9]

The second barrier is a lack of awareness of the benefits associated with the adoption of emissions-reducing technologies. This can be a problem even when the occupiers of buildings are the owners. The fragmentation of the industry is notable, with large numbers of competitors involved in the design, construction and maintenance of buildings. Again, information programs are the solution to this problem. The development of energy service companies (these are businesses that develop, install and finance projects aimed at improving the energy efficiency and reducing maintenance costs if facilities) could improve awareness of opportunities for increasing energy efficiency.

The third barrier is the low capital stock turnover in buildings. Emphasis needs to be given to what can be accomplished by the retrofit of existing buildings.

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[9] A second disjunction relates to commercial buildings. The design of many large commercial buildings typically involves an architect for the building envelope (roof, walls and foundation) and mechanical engineers for the heating, ventilation and air-conditioning systems.

The fourth barrier is the cost of adopting new technologies, which includes the cost of adapting production methods and organisation as well as the cost of training managers and employees. Carbon taxes would raise the rewards in relation to the costs, subsidies on new technologies would reduce the cost.

The fifth barrier relates to business process innovation in some parts of the services sector. Those sectors less open to the influences of globalisation are most likely to lag in the adoption of emissions saving technologies in the context of emissions taxes. Regulatory reforms to open these industries to the influence of globalisation and benchmarking of best practice energy management are two avenues of policy.

The Use of Specific Policy Instruments

Economic Instruments

The first choice for economic instruments in the building sector is the carbon tax. The carbon tax encourages decisions on building design and building use that: (i) increase energy-efficiency and (ii) reduce the emissions-intensity of energy consumption.

Carbon taxes will work more efficiently as a policy instrument if the price elasticity of demand for energy consumption is high. Elasticities of demand tend to be constrained by technical factors that limit the response of energy demand to price changes. A strategy for encouraging demand response is outlined in the addendum on demand response. Tax credits are an alternative economic instrument where political considerations preclude carbon taxes. In the United States, utility-based incentive programs for customers to purchase energy-efficient building products have been used. Specific assistance can be given to low-income groups for energy conservation (Brown et al. 2005).

Regulation

The design and construction of buildings is subject to regulations in most countries. The most important reason for such regulations is safety. Policy should endeavour to integrate energy-efficiency practices and principles into broader building regulations. This would imply the updating of building codes in particular. Appliance and equipment efficiency standards have been used with some effect in a number of advanced economies.

A second aspect of regulatory policy is connected with the issue of slow rates of capital stock turnover in buildings. Encouragement needs to be given to the retrofit of old buildings. The adoption of energy ratings on existing buildings might encourage the appearance of premium prices for high energy-rating buildings and provide incentives for energy-related retrofit of buildings.

Encouraging Commercial R&D

Subsidies for the purchase or installation of products incorporating particular technologies may be means of facilitating the take-up of desirable technologies so that market conditions reach a minimum critical mass for scale economies to be obtained.

Science and Technology Policy

The issues relating to science and technology policy are similar in the case of the building sector to that for the industrial sector.

Education and Information

Energy information programs aim to encourage the adoption of cost-effective energy efficiency and renewable energy technologies in the residential, business and government sectors. Programs include provision of information, raising awareness of the benefits of energy efficiency coupled with initiatives to encourage and facilitate actions that lead to improved energy efficiency. Benchmarking best practice in building energy management is a useful technique that can be readily employed in commercial and government buildings.

Efficiency improvements of end-use conversions technologies depend on the availability of new technologies and demand response from final consumers. Energy labelling schemes and energy performance standards are playing an important role in stimulating such efficiency improvements in a range of advanced economies (OECD 2003). According to IEA projections, the policies enacted since 1990 reduced OECD residential electricity consumption by 3.8% in 2000 and will go on to reduce it by 9.9% in 2010 and 12.5% in 2020 compared to what would have happened had they not been introduced.

Finally, the training of managers and employees in the building sector, particularly in relation to energy-efficient building design, would be desirable.

International Cooperation

International cooperation in policy would be especially useful in relation to the issue of energy use in providing standby power the appliances and equipment. Several features of standby power and the manufacture and marketing of the equipment that consumes it, argue for an international effort to reduce the losses attributable to it:

- standby power consumption by electrical equipment is a uniquely international issue because the manufacture of many of the appliances that use standby power typically involves many countries; and
- electronic devices are marketed internationally, so setting standby power use limits country by country would be unnecessarily difficult and costly.

Several policy instruments can be used to tackle the international problem of standby power consumption, ranging from labelling to imposing minimum performance standards, and from voluntary schemes to regulation. Many governments have already begun substantial programs to reduce standby power use, such as the EU, the US and Australia (OECD 2003).

With increasing globalisation of appliance and technology markets, international collaboration and cooperation on appliance policy is becoming an essential element of product markets. International policy coordination can generate a greater transparency and comparability in appliance standards, test procedures and labelling which would bring benefits for producers, consumers and governments alike. Several levels of cooperation are conceivable – collaboration in the design of tests, labels and standards; coordination of the program implementation and monitoring efforts; harmonisation of test procedures; and harmonisation of the energy labelling and standards levels used in the various programs.

Conclusions

The IEA Reference Scenario (IEA 2004) provides projections of energy consumption and CO_2 emissions from other sectors, which are dominated by building-related energy consumption, for the period up to 2030 under Business-As-Usual assumptions. The data is summarised in Table 4.

Table 4. Energy Consumption in Other Sectors and the IEA Reference Scenario

CO_2 Emissions from Other Sectors, Average Annual Rate of Growth	2002/2010	2010/2020	2020/2030	2002/2030*
OECD	0.6	0.4	0.3	8.3
Developing Economies	2.4	2.3	2.1	80.7
World	1.3	1.2	1.1	36.0
Energy Consumption by Other Sectors as a % of Total Final Energy Consumption	**2002**	**2010**	**2020**	**2030**
OECD	32.9	32.4	31.9	31.6
Developing Economies	46.8	44.8	43.2	42.2
World	39.2	38.3	37.7	37.4
Energy Source as a % of Energy Consumption by Other Sectors, World	**2002**	**2010**	**2020**	**2030**
Coal	3.5	2.8	2.1	1.7
Oil	18.1	17.8	17.7	17.6
Gas	20.3	20.3	20.1	19.8
Electricity and Heat	28.0	30.5	33.4	36.3
Renewables	30.1	28.6	26.7	24.7

Note: * percentage increase 2002 to 2030.
Source: Derived from IEA (2004, pp. 430-437, 478-483).

In the OECD, substantial increases in the potential energy requirements associated with annual growth in the building floor area that needs to be serviced of around 1.5 to 2.5%, is offset by considerable improvements in energy efficiency such that energy consumption increases by an average 1.0% per annum. The displacement of oil by electricity brings additional savings for end-point emissions, which are projected to rise by only 0.4% per annum.

In the developing economies, progress in reducing the growth of emissions is much more limited than the in the advanced economies. Over the projection period, CO_2 emissions are expected to increase by 80.7% compared with only 8.3% in the OECD economies. Factors contributing to this trend are:

- rapid growth in a number of leading developing economies;
- increases in the building floor areas consequent upon rapid economic growth;
- lags in the adoption of energy-efficient technologies in building design; and
- the decline in the relative importance of traditional biomass as a source of energy and its replacement, in part, by oil and gas.

In Table 5, data from the Optimistic Scenario for advanced economies complied in CSES (2004) indicates the extent of emissions-savings that could be achieved in the buildings sector. The key issue from a global viewpoint is how quickly these advances can be taken up by the developing economies.

Table 5a indicates that building-related emissions in the advanced economies are roughly stable up to 2020 and then decline at a rapidly accelerating rate up to 2050.

Table 5b indicates:

- the potential increase in the energy requirements of buildings that relate to increases in floor space would increase by 173% between 2000 and 2050;
- increases in energy efficiency made possible by the introduction of new technologies in building design and equipment used in buildings would reduce this prospective growth in energy requirements to below 92%;
- if we add to this changes in the source of energy used in buildings, GHG emissions would decline by 83%;
- fossil fuels as an energy source for buildings decline from 57.1% in 2000 to 5.7% in 2050; and
- electricity and heat as a source of energy increases from 38.9% to 78.2%, other renewables increases from 0.4% to 15.3%, and biomass decreases from 3.7% to 0.8%.

Table 5. Optimistic Scenario for the Advanced Economies

5a. Average Annual Rate of Growth of GHG Emissions from the Residential and Service Sectors

2000/2010	-0.1
2010/2020	0.0
2020/2030	-2.4
2030/2040	-4.6
2040/2050	-9.8
2000/2050	**-82.7**

5b. Contributions to the Trends in GHG Emissions from Industry, the Residential and Service Sectors, 2050

	Index	% change 2000/2050
Zero Improvements in Industry Sustainability	100.0	172.9
Increases in Energy Efficiency	70.2	91.5
Changes in Energy Source	9.2	-74.9
Combined Effects of Previous Two Effects	6.4	-82.7

Source: Based on CSES (2004, pp. 65-66).

ADDENDUM: ENCOURAGING DEMAND RESPONSE

Demand responses to price signals need to be encouraged in the processes that give rise to energy consumption. The technical issues relating to demand response principally relate to the final demand for electricity, and the main sources of demand for electricity are industrial processes and building use. The following comments are relevant to both these sectors.

The liberalisation of electricity markets has created competition in the generation and retailing of electricity and separated network functions into transmission and distribution. In such a system, there can be many beneficiaries of a customer's decision to provide price response. The key question remains how to quantify the benefits of demand response that are not currently captured in wholesale prices (e.g. avoided network congestion, lower price volatility and risk) and ensure economic gains are distributed efficiently and equitably amongst market participants.

As a consequence of post-reform market structures, the incentives to undertake demand response have been dispersed amongst the various parties. Consumers initially lack incentives to respond of behave efficiently and are most responsive to simple price discounting. Generators have little interest in demand response (except as a hedge to unplanned outages) and have dominant relationships with system operators (who effectively become responsible for real-time system balance), while peaking generators view demand response as direct competition. System operators, on the other hand, now seek demand response as a means to balance supply and demand economical and to keep the system reliable. Network operators may look to demand response to relieve network congestion and hence improve the local reliability and quality of supply, but incentives to do so may depend crucially on the treatment of demand response expenditures under rate-of-return formulae. Retailers can be interested in demand response as a means to balance more economically the demands of their consumers with the supplies they have contracted.

In any given market situation these different players will value a unit of demand response differently according to its purpose. Further more, it is ultimately consumers that make the decision whether or not to reduce their consumption of electricity at a particular moment of time. For the market to make efficient decisions all other participants who stand to gain from demand response have to signal to the consumers the value they place on a reduction in demand. Therefore the only way to obtain an economically efficient outcome is for all these parties to participate in some way in the price formation process. However this process, requiring exchange of value and price information between multiple parties, will call for significant investment in intra-party communications, metering systems and information technology which has thus far prevented multiple party interests to be consolidated.

This dispersal of value, and hence of market incentives, for demand response represents a clear market failure in liberalised electricity markets, and a source of economic inefficiency. Potential remedies to this market failure may involve revised market designs that provide a mechanism to aggregate the now-dispersed demand response values, thus enabling a private business case to be constructed for the necessary investment in demand response infrastructure. Alternatively, it may involve institutional investments and remedial policy interventions. As the analysis of the load response market in advanced economies indicates, disconnected markets, where the demand side fails to respond to tight supply side conditions and high price episodes, have already developed and that business models have not emerged to provide a natural market remedy (IEA 2003).

The introduction of a price-variable demand response does not necessarily lead to an overall reduction of electricity consumption. Conventional demand response programs are focussed on shifting load from peak to off-peak times, generating economic benefits, whereas energy efficiency programs generally seek to reduce loads, regardless of time-of-use. However, as knowledge of the consumer's capability for valuing electricity increases and pricing programs are refined, price signalling can in turn be used to encourage consumers to less wasteful use of electricity. Current estimates suggest that in addition to peak load shifting benefits derived from the introduction of time variable pricing, typical residential programs also deliver approximately 2% reduction in energy consumed (IEA 2003).

Technology will play an important role in the development of effective demand response markets for energy. Traditionally, most small customers have been provided with a basic accumulation meter that provides a single consumption figure for the period between readings. The liberalisation of markets has seen the value of electricity captured in wholesale markets according to timed intervals, reflecting the true cost of marginal production according to such externalities as primary fuel cost, weather, and time of day. These timed intervals at the wholesale level represent the smallest unit of timed electricity that could be used for tariff or billing purpose.

Minimum core functional requirements to enable the metering device to accommodate the basic forms of price-response tariff require additional accumulating registers to record timed periods of consumption, such as peak and off-peak usage. In addition, a timing capability is required to determine start and stop times for the timed periods. This switching capacity may be supplied by an internal clock device or by an external source via Radio (RF), Ripple Control (PLC) or Time-switch (clock).

The consumers of energy not only benefit from technology that accurately measures their demand for energy but will also benefit from technology that improves their capabilities for managing their demand load. For larger commercial and industrial customers, utility interfaces are often centred on traditional Buildings Energy Management Systems (BEMS) and increasingly on internet-served energy management applications. BEMS technologies are implemented to provide in-building and process efficiencies and as such are synergistic with the objectives of both system-led and market-led response programs. Furthermore, as the potential for load control emerged as a market resource, a new market emerged for instantaneous power monitoring and recording, with low cost devices for on-site and load management being introduced. Under load participation programs, the requirements for accurate settlement and performance measurement has increased the accuracy and security requirements of these monitoring and measurement devices in order to match on-site control with billed or contracted data.

Transmission or systems operators at either the local retail level or the national transmission level are required to perform complex load-scheduling and dispatch functions to ensure the reliability and security of supply. In traditional electricity markets this process has been developed almost exclusively with supply-side resources, with a consequent focus on generation performance characteristics.

To establish demand resources on an equal footing with supply side resources at the control desk of network operators would require high degrees of process – and technology – integration. Network operators often use technical standards and dispatch control technologies and software, which have been developed and refined over the course of many years of market operation. In this situation, only very large individual consumers will have the required resources to perform the necessary technology assessments and investments to enable direct participation in Independent System Operator markets. It therefore follows that the effective integration of smaller demand resources in the delivery of network operation services will only become feasible when an intermediary has a scale of aggregated response to justify such investments.

Whilst the emergence of such aggregators is feasible, it is becoming clear that there may not be enough 'critical mass' representation from the demand-side to support and sustain such initiatives, at least without stronger incentives for such representation. Network operators may be willing to adapt and modify their control and technology requirements; however, greater demand will be required from consumers to drive such change. Regulators and public bodies should give consideration to the formation of research programs to consider the potential for increased demand side participation, and particularly consider the potential to adapt Independent System Operator systems to specific demand-side practices and technical approaches.

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