NEW ENERGY TECHNOLOGIES

Measuring potential impacts in APEC

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foreword

As the fastest growing energy consuming region in the world, APEC faces a number of challenges as it strives to achieve economic growth in a sustainable manner. Energy underpins every form of economic activity and the linkage between energy use and the environment is important. This is particularly the case in the majority of APEC economies, where the use of fossil fuels is forecast to continue to play a key role in energy supply over the coming decades.

Currently, the APEC region is characterised by electricity generation and steel making capacity of mixed vintage, with corresponding variation in operational and environmental performance. Driven by a range of factors, the pattern of technology uptake has led to a large efficiency gap between current and best practice in these sectors. However, the scale of new capacity additions required to meet projections of energy demand provides considerable opportunity to close this efficiency gap if the appropriate incentives are in place to both develop and adopt more advanced technologies.

The objectives in this study are to assess the current status of energy technologies in the electricity and iron and steel sectors in APEC economies and to analyse alternative scenarios of the future development and adoption of new technologies. The focus of the study is on examining the role that advanced technologies might play in reducing future growth in energy consumption and greenhouse gas emissions in the APEC region. The study demonstrates that there could be considerable energy savings and environmental benefits from the accelerated development and diffusion of advanced technologies. It also highlights the need for continued emphasis on research and development, as well as the need for governments to create policy settings that facilitate investment in new technologies. The study also indicates that regional cooperation can be an important driver of technology development, transfer and adoption in the APEC region.

Brian S. Fisher
Executive Director
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glossary

agglomerated iron ore	Large iron ore pieces that have been processed from iron ore particles. These iron ore pieces are produced because iron ore is a powdery material that is difficult to handle and transport because of dusting and decomposition.
atmospheric concentration	A measure of the amount of greenhouse gases present in the earth's atmosphere, per unit volume.
bagasse	The fibrous residue of the sugar cane milling process that is used as a fuel (to raise steam) in sugar mills.
base load	Continuous load at or near capacity. Normally the ratio of energy production of a generating plant to the total energy production would be in excess of 60 per cent.
bottom-up model	Economic model using an engineering based approach. Contains detailed cost and performance data of specific energy technologies and services.
capacity	The rated continuous load-carrying ability of power generation equipment; sometimes referred to as maximum continuous rating (MCR) or continuous maximum rating (CMR).
carbon capture and storage (CCS)	The capture of carbon dioxide from power generation plants with subsequent permanent storage in geological or ocean sites.
carbon constraint	A limit placed on the amount of carbon dioxide that can be emitted either in the form of a tax or a quantitative restriction.
carbon intensity of fuels	A measure of the amount of carbon dioxide emitted per unit of fuel burnt. Reflects the original carbon content of the fuel.
casting	The action of pouring molten steel into a mould in order to form solidified steel in specific shapes as required.
cogeneration/ combined heat and power	Simultaneous production of both useful thermal energy (heat, typically as steam) and electricity.

CO_2	Carbon dioxide. The principal anthropogenic greenhouse gas.
DFCCC	Direct fired coal combined cycle. A gas turbine used to generate electricity by burning ultra clean coal directly in a combined cycle gas turbine, reaching higher efficiencies than pulverised coal turbines.
discount rate	The factor that translates expected benefits or costs in any given future year into present value terms.
emissions intensity	Emissions of greenhouse gases per unit of output.
energy intensity	Energy consumption per unit of GDP.
flue gas	Exhaust gas from combustion.
FBC	Fluidised bed combustion based power generation plant that burns coal in a reactor of heated particles suspended in a gas flow.
final energy consumption	The total amount of energy consumed in the final or 'end use' sector. It is equal to total primary energy consumption less energy consumed or lost in conversion, transmission and distribution.
fossil fuel	Fuel extracted from a hydrocarbon deposit that was derived from living matter in the remote geological past. For example, oil, petroleum and natural gas.
GHG	Greenhouse gas. Any gas in the atmosphere that absorbs and re-emits infrared radiation. Major greenhouse gases include water vapor, carbon dioxide, methane and nitrogen oxides.
HHV	Higher heating value. The amount of heat recovered when the products of complete combustion are cooled to the initial temperature of the air and fuel.
hydrogen	Colorless, odorless, flammable gas.
IGCC	Integrated gasification combined cycle power generation plants that gasify coal to produce a syngas that is cleaned and burned in a gas turbine, generating electricity. Exhaust heat is used to drive a steam cycle, generating additional electricity.
ingots	A form of semifinished steel that is created by pouring liquid steel into moulds where it solidifies. Previously, steel was formed into ingots and then later cast in steel shapes

	such as slabs, billets and blooms (Mesteel.com). But with the introduction of continuous casting, the production of ingots is no longer required, as steel shapes can be directly cast from molten steel.
iron ore fines	Fine grains of iron ore used to produce pig iron. Often the fines are unsuitable for steel production, so they are processed into larger agglomerated iron ore pieces. New direct reduced iron and smelt reduction processes that enable the production of pig iron from iron ore fines without agglomeration are in development.
levelised electricity generation cost	The discounted sum of fuel, operating and investment costs 'levelised' or averaged over the projection period.
lignite	Coal with high moisture content. Often referred to as brown coal.
lignite drying	A drying process to reduce the moisture content of brown coal and increase combustion efficiency.
LHV	Lower heating value. A standard measure of the efficiency of an electricity generation plant; and equivalent to net calorific value. Corresponds to the number of heat units liberated per quantity of fuel burned in oxygen, minus the latent energy contained in water vapor (exhaust gas) that is produced when hydrogen (from the fuel) is burned. The thermal efficiency of a coal fired power plant based on LHV is typically 2–3 percentage points higher than its thermal efficiency based on HHV.
NGCC	Natural gas combined cycle power generation plants that burn natural gas in a turbine to generate electricity. The waste gases are recovered and used to generate additional electricity in a steam cycle.
offgrid	Not connected to the electricity grid.
pc	Pulverised coal power generation plants that combust pulverised or milled coal at high temperatures, raising high pressure steam and generating electricity using a steam turbine.
peak load electricity	The supply of electricity to meet maximum demand during a specific period of time.

primary energy	Equal to the consumption of commercial energy (excluding biomass in non-OECD economies) in its initial form after production or import.
primary fuels	The forms of energy obtained directly from nature. They include nonrenewable fuels such as black coal, brown coal, uranium, crude oil and condensate, naturally occurring liquid petroleum gas, ethane and natural gas, and renewable fuels such as wood, bagasse, hydroelectricity, wind and solar energy.
reduction	The use of natural gas or coal to remove oxygen from iron ore to produce a more pure form of iron.
renewable electricity	Electricity derived from natural processes that theoretically cannot be exhausted. For example solar, wind, hydropower, geothermal and biomass.
scrap (ferrous)	Material containing iron that can be remelted and recast into new steel. Scrap is the predominant iron feedstock for electric arc furnace minimills and also provides about 25 per cent of the iron feedstock for blast furnaces.
secondary fuels	Fuels produced from primary or other secondary (or derived) fuels by conversion processes to provide the energy forms commonly consumed. They include refined petroleum products, thermal electricity, coke, coke oven gas, blast furnace gas and briquettes.
slabs, blooms and billets	Various steel shapes that are formed after molten steel is cast into a mould. Blooms and billets are formed for the production of rods, bars and sections, while slabs are formed to produce sheet, plates and strip. Historically these steel shapes were formed after steel ingots were cast, but with the introduction of continuous casting, the formation of billets, blooms and slabs can occur directly from the casting of molten steel.
specific energy content	The primary energy equivalent of energy consumed by final energy users. It is calculated by adjusting the electricity consumed in a process by a conversion factor representing the average thermal efficiency of electricity generation. That is, 1 GWh of electricity generated at 40 per cent efficiency has a specific energy content of 2.5 GWh (1/0.4 = 2.5).

steel charge	The act of loading material used in the production of steel in a vessel. For instance, iron ore, coke and limestone are charged into a blast furnace were molten steel is produced.
subcritical steam	Subcritical (steam) refers to steam temperature and pressure below the critical point of water, typically in the range of 520–550°C and 16–18 megapascals.
supercritical steam	Supercritical (steam) refers to steam temperature and pressure above the critical point of water, typically in the range of 550–566°C and 23–30 megapascals.
thermal (or conversion) efficiency	The ratio of electricity produced to each unit of fuel used of fuel used. Usually expressed as a percentage.
thermal efficiency of a power station	The electrical energy leaving the station divided by the fuel energy entering the station. It is essentially a measure of the overall fuel conversion efficiency for the electricity generation process.
top down model	Economic model that evaluates the final demand for goods and services, and the supply from main sectors (energy, transport, agriculture and industry) using aggregate economic variables.
total installed electricity generation capacity	The sum of the capacity of each electricity generation unit making up a power generation plant, where capacity is defined above.
ultra clean coal	Coal that contains less than 1 per cent ash and has had virtually all mineral impurities chemically removed. UCCs can be pulverised and fed directly into gas turbines.
USC	Ultra supercritical (steam) refers to steam temperature and pressure above 566°C and 30 megapascals.
waste gases	Gases released from various steel making processes. Where these gases have a high energy content or heat value, they are often captured for reuse elsewhere in the production process.

summary

- Accelerating the development and uptake of advanced technology in the energy sector has the capacity to reduce the growth in energy consumption and greenhouse gas emissions in the APEC region.

- Total primary energy consumption in APEC under 'business as usual' assumptions is projected to grow at 2.1 per cent a year between 2002 and 2030. Much of this growth will be driven by energy intensive industries such as electricity generation and iron and steel production.

- The electricity and steel industries in the region are characterised by plant of mixed vintage, with corresponding variation in operational and environmental performance. However, the scale of required capacity additions over the next three decades, particularly in electricity generation, provides considerable potential to improve the overall efficiency of the power generation and steel making sectors in APEC economies by adopting more advanced technologies.

- Accelerated development and adoption in APEC of more advanced technologies could reduce growth in energy consumption in the electricity generation sector by 40 per cent by 2030, and halve the growth in energy consumption in the steel making sector. This could lead to energy savings of more than 500 million tonnes of oil equivalent (Mtoe) each year in these industries by 2030.

- The extent to which this potential can be realised is dependent on two key factors: research to develop more advanced technologies; and appropriate institutional settings within each economy to facilitate uptake of new technologies.

Energy sectors of the APEC region

Membership of the Asia Pacific Economic Cooperation (APEC) forum includes some of the largest and fastest growing economies in the world. Rapid economic growth in APEC is likely to lead to strong growth in energy consumption in the coming decades. As the fastest growing energy consumer in the world, the APEC region faces a number of challenges including the need for large investments in energy infrastructure; increasing dependency on imported energy; and increasing local and global impacts of energy related pollution, including greenhouse gas emissions associated with the burning of fossil fuels.

The part of the energy sector experiencing the most rapid growth over recent years has been demand for electricity by industrial, commercial and residential consumers. Electricity is a key component of industrialisation and improvements in living standards. As economies become industrialised, their growth is increasingly powered by advanced industrial technologies that rely more heavily on electricity. Also, as income levels rise, people seek greater convenience and comfort in their life, which adds to the demand for electricity. On average, electricity consumption in the region has grown by around 4 per cent each year since 1980. Much of this regional growth has been driven by growth in low income economies. Because of its abundant supplies and competitive cost, coal is likely to remain a major fuel for electricity generation in the APEC region in the coming decades.

Iron and steel production accounted for approximately 7 per cent of final energy consumption in the APEC region in 2002. Expansion in iron and steel production, a large consumer of energy, and electricity in particular, is a major contributor to growth in energy consumption. Energy consumption in the iron and steel sector is projected to grow at an average rate of 1.6 per cent a year over the period to 2030. China is the world's largest steel producer, accounting for more than 20 per cent of world production in 2002, and much of the growth in energy consumption in the steel making sector is projected to occur in China and other low income economies.

There is limited information readily available on the vintage of existing electricity generation and steel making plant in many APEC economies. The dominant technology in electricity generation — subcritical pulverised coal plant — is now regarded as relatively inefficient compared with the newer, more advanced technologies that are now available. In general, however, as new capacity has been added and existing capacity refurbished, the average efficiency of power generation and steel production has increased in many economies over the past decade. In others, however, efficiencies are well below world's best practice. Most APEC economies have power generation and steel production plant of mixed vintages, with corresponding variation in operational and environmental performance, even after accounting for structural issues such as fuels used in electricity generation, and the ratio of iron production to steel production.

Japan and the Republic of Korea have adopted highly efficient electricity generation and steel production technologies, driven in part by high energy costs and strict environmental standards that have encouraged power generators and steel producers to make energy saving investments. Economies such as China and the Russian Federation generally have lower thermal efficiency and higher energy consumption in both electricity generation and steel production than developed economies. In China and Russia, a large share of generation and production is undertaken using older plant and low energy costs have reduced the incentives to invest in energy saving technologies.

The pattern of uptake of technologies has led to a large efficiency gap between current and best practice in these sectors. Considering the scale of energy use across APEC in both the electricity generation and steel making sectors, the efficiency gap has major implications for required investment in energy infrastructure, energy prices and energy security concerns, as well as for the environmental consequences of energy consumption.

The projected growth in energy consumption in APEC will necessarily be supported by significant investment in infrastructure, particularly in power generation and transmission capacity, and in emission control technologies in coal fired power plants. While much of this investment will be in new infrastructure, there will also be a need to refurbish or replace existing infrastructure as it reaches the end of its economic life. While growth in steel making capacity is likely to be less investment intensive than in the electricity sector, there will be significant additions to capacity in some of the region’s economies.

In the case of electricity generation the scale of required capacity additions over the next three decades provides considerable potential to improve the overall efficiency of the power sector of an economy by adopting more advanced technologies. The scale of capacity additions in the iron and steel sector across APEC is not projected to be as large as those for electricity generation. To some extent, this limits the potential for improving the average energy efficiency of the steel making sector in an economy as new capacity will be brought on slowly. However, much of the projected growth in steel production will be located in economies where current production processes are well below best practice and these economies provide the greatest potential to reduce growth in energy consumption and greenhouse gas emissions through the adoption of more advanced steel making technologies.

Study objectives and analytical framework

The objectives in this study are to assess the current status of energy technologies in the electricity and iron and steel sectors in APEC economies and to analyse alternative scenarios of the future development and adoption of new energy and environmental technologies in these sectors. The role that advanced technologies might play in reducing future growth in energy consumption and greenhouse gas emissions in the APEC region is examined.

The focus of the study is the electricity and iron and steel sectors because they are large energy consumers. The study focuses only on supply side technologies and does not address the considerable potential for demand side measures such as electricity conservation to contribute to reducing the growth in APEC energy consumption and greenhouse gas emissions.

The future prospects of key technologies in the electricity and iron and steel sectors are qualitatively assessed by identifying the main factors that drive the commercialisation of new technologies, and examining the main factors influencing the dispersion of new technologies both within, and between APEC economies.

The analysis of the impacts of new energy and environmental technologies reported in this study is based on simulation results from ABARE's global trade and environment model (GTEM). GTEM is a dynamic, multiregion, multisector, general equilibrium model of the world economy. A GTEM reference case or 'business as usual' simulation provides a benchmark against which the impacts of policy changes can be assessed. The reference case projects growth in key variables in each region in the absence of policy changes. In this study, the reference case represents the likely outlook for APEC energy production, consumption and trade in the absence of measures to alter the development, dispersion, and uptake of energy and environmental technologies in the electricity and steel making sectors. Three technology adoption scenarios are compared with the reference case to assess the impacts of more rapid technology development and uptake.

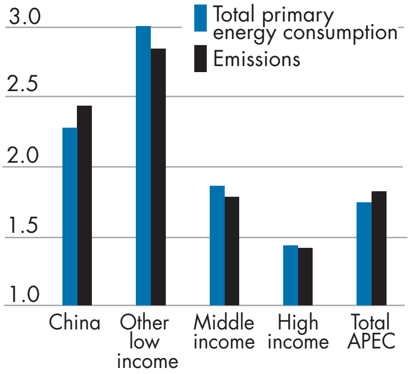
Energy consumption and greenhouse gas emissions under the reference case

Total primary energy consumption in the reference case is projected to grow at an average rate of 2.1 per cent a year between 2002 and 2030. This growth in energy consumption is matched by similar growth in greenhouse gas emissions in most APEC economies (figure A).

Energy consumption and greenhouse gas emissions are projected to expand most strongly in China and other low income APEC economies as a result of relatively rapid economic growth and increased demand for personal services in these economies. Because of its rapid growth and large initial energy consumption, China alone is projected to account for around 40 per cent of the growth in energy consumption and almost half the growth in greenhouse gas emissions in APEC between 2002 and 2030.

A **Change in APEC energy consumption, 2002–30**

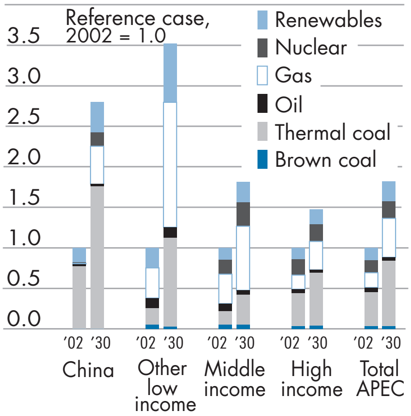
Reference case, 2002 = 1.0



Electricity generation

Changes in the composition of fuel consumption in APEC over the reference case are driven to a large extent by growth in electricity generation across the region. Growth in electricity output and its implications for fossil fuel consumption are largely influenced by the stage of development of economies throughout the region. Over the reference case, China and other low income APEC economies are projected to account for more than half the growth in electricity generation in the region, despite generating only 20 per cent of the region's electricity in 2002 (figure B). In China, this increased output is characterised by increasing shares of natural gas and renewable energy sources in the electricity fuel mix. In other low income economies, the role of black steaming coal in electricity generation is projected to increase, reflecting the continued competitiveness of black steaming coal in providing base load power. The cost competitiveness of natural gas turbines for peaking capacity is one reason for the increasing share of natural gas in the electricity fuel mix in high income APEC econo-

B **Change in APEC electricity generation, by fuel**



mies, where peaking capacity is projected to account for a larger share of new power generation capacity than in other economies.

This growth in energy consumption is matched by similar growth in greenhouse gas emissions in most APEC economies. This is moderated to a degree by improvements in energy efficiency, particularly in less energy efficient economies where opportunities for rapid technological catchup exist. Efficiency improvements are particularly large in middle income economies, mainly because of rapid output growth and technological catchup in the Russian Federation, but also because of the high efficiency of new generation capacity in Korea and, to a lesser extent, Mexico.

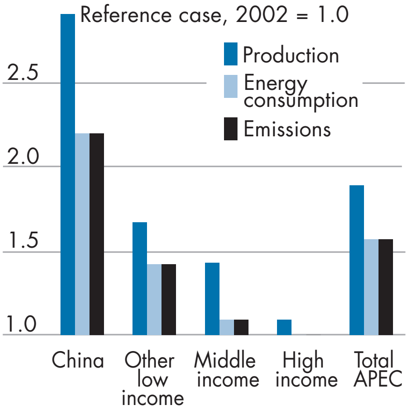
Smaller efficiency improvements occur in the low income economies, reflecting the high initial efficiency of gas fired power generation in a number of low income economies, such as Indonesia, Thailand and Viet Nam. In high income economies, efficiency improvements are projected to occur most rapidly in economies where the initial efficiency of gas fired power generation capacity is low, such as Australia and the United States. The improvement in the efficiency of black coal fired electricity generation is projected to grow at a slower rate than natural gas fired electricity over the reference case.

Iron and steel production

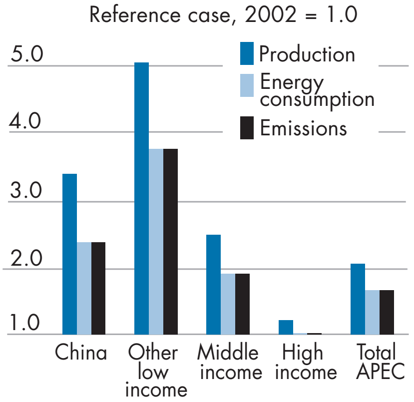
Similarly, efficiency improvements in the production of iron and steel are projected to reduce energy consumption and greenhouse gas emissions in both blast furnace and electric arc furnace production (figures C, D).

China is projected to be the main source of the improvement, with most of the rest of the improvement projected to occur in middle income economies, particularly the Russian Federation. In the higher income APEC economies, slow growth in the output of blast furnace based steel is projected to

C Change in APEC blast furnace steel, 2002–30



D Change in APEC electric arc furnace based steel, 2002–30



be almost matched by improvements in the energy efficiency of this process route and, as a result, the energy consumption and greenhouse gas emissions from blast furnace based steel production are projected to remain relatively constant over the projection period.

Although accounting for much less new steel production capacity in absolute terms, the output of electric arc furnace based steel is projected to grow more rapidly than blast furnace based steel over the reference case, particularly outside China, increasing from almost 31 per cent of APEC steel production in 2002 to around 33 per cent in 2030. As a result of this increased output growth and the impact of new casting and rolling techniques on the energy efficiency of this process route, the energy efficiency of electric arc based steel making in each APEC economy is projected to improve more rapidly over the reference case than that of blast furnace based steel production.

Although the share of steel produced in electric arc furnaces in China is expected to remain relatively constant over the period, China is still projected to account for more new electric arc based steel production than any other APEC economy and the energy efficiency of its electric arc sector is projected to improve considerably over the period.

Impacts of alternative paths of technology uptake

Three technology adoption scenarios are developed in the study in which key assumptions on technology development and uptake are modified from the reference case.

The first scenario examines the impact of the accelerated development of advanced technologies that leads to significant improvements in the energy efficiency of electricity generation and steel making in the APEC region (the 'high technology development' scenario). The second scenario examines the impact of more rapid technology diffusion throughout the APEC region (the 'accelerated adoption' scenario). The third scenario, a combination of the two previous scenarios, examines the impact of both the accelerated development of advanced technologies and its more rapid diffusion (the 'high technology with accelerated adoption' scenario).

Electricity generation

Results from the scenarios indicate that the accelerated development and diffusion of more advanced electricity generation technologies have the potential to reduce the growth in fossil fuel consumption in the electricity sector in APEC by more than 40 per cent, or 460 million tonnes of oil equivalent (Mtoe), relative to the reference case. This equates to almost 12 per cent of the total growth in energy consumption in APEC over the reference case.

Key results for electricity generation in the APEC region under different technology development and diffusion assumptions are presented in table A.

High technology development scenario

Improvements in thermal efficiency under the high technology development scenario are projected to lead to significant reductions in the amount of fossil fuels consumed in electricity generation — of about 344 Mtoe, or 12 per cent, at 2030 relative to the reference case. This energy saving is equivalent to more than 30 per cent of the growth in fossil fuel consumption in the electricity sector in APEC and would lead to a reduction in greenhouse gas emissions of about 11 per cent relative to the reference case.

The reduction in energy consumption is projected to be largest for natural gas. This is attributable to two factors: the large absolute improvement in

A Electricity generation, energy consumption and greenhouse gas emissions, by scenario, 2002 and 2030

	Reference case		High technology development		Accelerated adoption		High technology development with accelerated adoption	
	2002	**2030**	**2030**	**2030**	**2030**	**2030**	**2030**	**2030**
	Mtoe	Mtoe	Mtoe	% diff	Mtoe	% diff	Mtoe	% diff
Energy consumption								
Brown steaming coal	92	87	79	–9.0	86	–2.0	78	–10.4
Black steaming coal	1 065	1 775	1 616	–9.0	1 689	–4.8	1 528	–13.9
Oil	135	98	95	–2.7	98	–0.3	95	–3.0
Gas	480	917	743	–19.0	868	–5.4	716	–21.9
Total	1 772	2 877	2 533	–12.0	2 740	–4.8	2 417	–16.0
	Mt CO_2e	Mt CO_2e	Mt CO_2e	% diff	Mt CO_2e	% diff	Mt CO_2e	% diff
Greenhouse gas emissions	6 379	10 753	9 545	–11.2	10 264	–4.5	9 097	–15.4

the thermal efficiency of gas fired electricity generation capacity in the scenario; and the use of natural gas combined cycle (NGCC) technology, which is projected to supply around half of new electricity generation capacity in APEC over the reference case.

Accelerated adoption scenario

This scenario investigates the possible implications of removing potential barriers to the adoption of best practice energy efficient technologies throughout the APEC region. In this scenario, larger energy efficiency improvements are assumed in economies where the energy efficiency gap between new capacity and best practice capacity in the reference case is greater. The results highlight the importance of technology transfer, particularly in economies away from the technological frontier, in reducing growth in energy consumption and greenhouse gas emissions.

In the electricity sector, the more widespread diffusion of advanced electricity generation technologies throughout APEC is projected to reduce the amount of fossil fuels consumed in electricity generation by almost 5 per cent (137 Mtoe) relative to the reference case at 2030. As with the high technology scenario, the largest differences in energy consumption are projected to occur in natural gas fired electricity generation, because natural gas technologies are introduced more rapidly than other technologies. This reduction in energy consumption is projected to lead to a reduction in greenhouse gas emissions of more than 4 per cent, relative to the reference case.

High technology development scenario with accelerated adoption

In this scenario the combination of more rapid technology development and adoption, as modeled individually in the previous two scenarios, is projected to result in larger improvements in the efficiency of fuel use in the electricity sector than observed in the previous scenarios.

In the electricity sector, the successful development and more widespread adoption of advanced electricity generation technologies is projected to reduce fossil fuel consumption in electricity generation in APEC by 460 million tonnes of oil equivalent at 2030. This energy saving is projected to reduce the growth in fossil fuel consumption by the electricity sector in APEC by more than 40 per cent relative to the reference case. This equates to more than 10 per cent of the total growth in energy consumption in APEC over the reference case. The largest efficiency improvements are projected to occur in natural gas fired electricity generation. In this scenario the consumption of natural gas in electricity generation in APEC is projected to fall by 22 per cent relative to the reference case at 2030, while the consumption of steaming coal in electricity generation is projected to fall by 14 per cent relative to the reference case at 2030.

Iron and steel production

Accelerated development and diffusion of advanced technologies could reduce energy consumption by almost 20 per cent in the APEC steel sectors at 2030, relative to the reference case. This equates to halving the growth in energy consumption in the steel industry relative to the reference case and could lead to reductions in greenhouse gas emissions of almost 20 per cent. Key results for iron and steel production in the APEC region under alternative technology development and diffusion scenarios are presented in table B.

High technology development scenario

In the steel industry, the accelerated development of advanced energy efficient technologies in this scenario is projected to reduce the costs of steel production in APEC, leading to increased steel demand throughout the region. These developments are also projected to change the competitiveness of steel producers within APEC and, hence, increases in steel production are not uniform across the region. The output of steel is projected to increase most in the more energy efficient high and middle income APEC economies where electric arc furnaces account for a large share of total steel production, and to fall slightly in low income economies where steel production is less energy efficient and where integrated steel making technologies dominate.

The reduction in energy consumption at 2030, relative to the reference case, under the high technology scenario is around 15 per cent for both integrated and electric arc production processes. This could lead to an energy saving of around 68 Mtoe at 2030, relative to the reference case. For both technologies, these energy efficiency improvements and resulting greenhouse gas emission reductions are larger in the high and middle income APEC economies.

B Iron and steel production, energy consumption and greenhouse gas emissions, by scenario, 2002 and 2030

	Reference case		High technology development		Accelerated adoption		High technology development with accelerated adoption	
	2002	**2030**	**2030**	**2030**	**2030**	**2030**	**2030**	**2030**
	Mtoe	Mtoe	Mtoe	% diff	Mtoe	% diff	Mtoe	% diff
Production								
Integrated minimill	385	725	718	–0.9	734	1.2	725	0.0
Electric arc furnace	171	351	372	6.0	352	0.2	376	7.1
Total	556	1076	1090	1.3	1 086	0.9	1 101	2.3
	Mtoe	Mtoe	Mtoe	% diff	Mtoe	% diff	Mtoe	% diff
Energy consumption								
Integrated minimill	260	408	346	–15.2	387	–5.1	328	–19.7
Electric arc furnace	26	44	37	–14.8	41	–5.2	35	–19.1
Total	286	452	384	–15.1	429	–5.1	363	–19.7
	Mt CO_2e	Mt CO_2e	Mt CO_2e	% diff	Mt CO_2e	% diff	Mt CO_2e	% diff
Greenhouse gas emissions	740	1 172	995	–15.1	1 114	–4.9	945	–19.4

Accelerated adoption scenario

The accelerated adoption of more efficient technologies is projected to lead to a reduction in energy consumption in the steel making sector of around 5 per cent at 2030, or 23 Mtoe, relative to the reference case.

Reflecting the importance of technology choice in the steel industry, the increased uptake of more efficient technologies in economies away from the technology frontier is projected to lead to more rapid growth in steel production but slower growth in energy consumption than that in the reference case. These improvements are projected to be concentrated in low and middle income economies that would otherwise introduce less energy efficient steel production capacity. Also, because more of the new integrated steel making capacity is introduced in economies away from the technology frontier, this accelerated adoption is projected have most impact on energy efficiency in the integrated steel making sector. Consequently, the energy efficiency of the least energy efficient integrated steel producers, Chile, China, Peru and the Russian Federation, is projected to improve by the largest margin, relative to the reference case at 2030.

High technology development scenario with accelerated adoption

In the steel industry, the accelerated adoption of the advanced steel production technologies successfully commercialised in the high technology development scenario is projected to lead to increased steel production relative to the reference case, while also halving the growth in energy consumption by the steel industry relative to the reference case. Energy savings of up to 89 Mtoe at 2030, relative to the reference case, could be achieved under this scenario.

As in the accelerated adoption scenario, efficiency improvements are largest in economies that would not have otherwise introduced the most energy efficient steel production technology. In China, for example, the energy efficiency of electric arc furnace steel production is projected to improve by 28 per cent relative to the reference case at 2030, while in Japan the energy efficiency of electric arc furnace steel production is projected to improve by around 22 per cent relative to the reference case at 2030.

These energy efficiency improvements reduce the cost of steel production throughout the region, which is projected to increase steel demand in APEC by about 25 million tonnes (2.3 per cent) relative to the reference case at 2030. Because these developments improve the competitiveness of electric arc furnace steel production relative to integrated steel production, most of this additional steel demand is met by electric arc furnace capacity. As a result, the production of steel in electric arc furnaces is projected to grow more rapidly than in the high technology scenario.

Key policy implications

The findings in this study indicate a potential role for technology in reducing energy consumption and greenhouse gas emissions in the APEC region. The results from the economic modeling indicate that the development and accelerated diffusion of new technologies in the power generation and steel sectors have the potential to significantly reduce growth in energy consumption in APEC economies as well as in greenhouse gas emissions. In the electricity sector, these developments have the potential to reduce the growth in fossil fuel consumption in APEC by around 40 per cent over the period 2002 to 2030. In the steel sector, these developments could halve the growth in energy consumption over this period.

The current capital structure of electricity generation is characterised by technologies that perform below world's best practice for thermal power generation in many APEC economies. The dominance of fossil fuels, and coal in particular, in the fuel mix for electricity generation is the reason why this sector contributes more carbon dioxide emissions than any other sector. Similarly, the energy intensive steel making sector is characterised by outdated and inefficient technology in many APEC economies. As with electricity, much of the growth in capacity will be required in economies at earlier stages of development such as China and the Russian Federation. The scale of required capacity additions across the APEC region and the size of the gap between current and world's best practice energy efficiency represent a significant opportunity to reduce energy consumption and greenhouse gas emissions through supply side technological advancement in both the electricity generation and steel making sectors.

Facilitating technology development, transfer and adoption

Continued emphasis on research and development of advanced technologies is a key aspect of realising the benefits of improved efficiency and environmental performance in the power generation and steel making sectors. Within each economy, appropriate incentives are required to facilitate both private and government expenditure on research and development. There are many factors that impede investment in research, including the uncertainty associated with developing a successful innovation, long time lags between initial investment and commercial return, and, in some economies, the inability to capture the commercial benefits of an innovation because of inadequate intellectual property laws. It is critical for individual economies to establish legal frameworks that protect intellectual property. The greater the coverage, duration and the enforcement of these rights the greater the incentive to invest in the development of advanced technologies.

The role of government in realising the potential benefits of advanced technologies extends beyond facilitating research and development to setting an appropriate environment for investment in new capital. In general, policy settings that promote long term economic growth will underpin investment in human, industrial and natural capital and promote the development and adoption of more efficient technologies. The drivers and impediments to the adoption of technology presented in this report highlight the need to establish stable, transparent and predictable legal, fiscal, regulatory and trade regimes to facilitate investment. Given the wide range of avenues for government policy to influence technology development, transfer and adoption, it is clear that a coordinated policy approach is important in providing a clear set of incentives.

The transfer of advanced technologies will be important in helping to close the energy efficiency gap between less technologically advanced economies and those that have developed or adopted more advanced technologies. The adoption of new technologies will be particularly important for developing economies. As much of the innovation of energy and environmental technologies occurs in a handful of developed economies, most economies will be dependent on others for access to advanced technologies.

Speeding up the rate of transfer and adoption of new or leading edge technologies from innovating economies to those economies that are less technologically advanced is a key aspect of realising the potential for technology to reduce growth in energy consumption and greenhouse gas emissions.

The role of international collaboration and coordinated research planning has been explored in this study as a mechanism to increase the rate of development and uptake of more energy efficient technologies. The sharing of intellectual capital through collaboration and the avoidance of duplication will promote ideas and lower the costs of research and development.

Further, collaboration is a means of spreading risk and, hence, managing the risks associated with a large scale research and development project. Foreign direct investment can also be an important driver of technology transfer as it can reduce the cost of gaining access to or information on new technologies.

Through APEC regional cooperation, developing economies may have access to advanced energy and environmental technologies that would not otherwise have been available. Regional accords between APEC economies could increase the number of economies from which technology may be sourced, as well as allow access to a wider range of technological innovation.

For the APEC region as a whole, the economic and environmental benefits of advanced energy technologies are significant. There are, however, impediments to technology transfer that will need to be addressed in order to reap the potential benefits of technology transfer and adoption. Any attempts to promote the diffusion of technologies will need to address barriers to investment using a comprehensive approach, recognising that impediments will manifest themselves differently in different economies, and that identification and prioritisation of barriers need to be economy specific. Many such barriers to technology transfer could potentially be reduced if governments, acknowledging the economic and environmental benefits of cooperation, worked together to overcome them.

1

introduction

- Member economies of the Asia Pacific Economic Cooperation (APEC) forum include the world's largest producers and consumers of energy (the United States, the People's Republic of China and the Russian Federation), the largest exporter of coal (Australia), liquefied natural gas (Indonesia), and the largest net importers of energy (Japan and the United States).

- APEC's membership also encompasses some of the most rapidly expanding economies in the world. Economic growth in the region has averaged around 3.4 per cent a year over the past two decades.

- Combined with rapid industrialisation, the growing demand for energy services generated by rising per person incomes has led to strong expansion in energy consumption. APEC now accounts for around 60 per cent of total world primary energy consumption.

The role of energy in APEC economies

Achieving economic growth in a sustainable manner is a challenge faced by all APEC economies. Energy is widely recognised as a crucial factor in the interrelated economic, social and environmental objectives of sustainable development — it underpins every form of economic activity and is a necessary input to growth. The linkage between energy use and the environment is an important one, as energy use affects the quality of the environment at a local, regional and global level, both directly and indirectly. This is particularly the case in the majority of APEC economies, where the use of fossil fuels is forecast to continue to play a major role in energy supply over the medium to longer term.

At the same time, a major issue on the international policy agenda is to develop an effective global response to the threat of human induced climate change. Finding a solution that meets the principles of environmental effectiveness, economic efficiency and equity is a challenge that all APEC economies face. Technology development and transfer, particularly in the energy sector, will play a crucial role in meeting this challenge because of its capacity to contribute to greenhouse gas emissions abatement while allowing for economies' aspirations for economic growth. Within the energy sector the adoption of new technologies may act to increase energy efficiency, change the fuel mix or reduce unwanted environmental outputs. This is particularly important in developing economies, which are likely to contribute the major share of greenhouse gas emissions in coming decades. Technology provides potential avenues to combine national policy goals, such as local pollution control, with the international policy goal of greenhouse gas emission abatement.

As a result, public policies that affect the development and transfer of new technologies may, over the long term, be one of the most important tools for environmental protection. Understanding the drivers of investment in innovation and the impediments to technology dispersion is critical to implementing appropriate policies to facilitate technology adoption. Given that much of the research and development in new technologies is likely to take place in the developed world, an important issue is how to ensure that new or leading edge technologies are transferred to and widely adopted in developing economies, both to enhance technical energy efficiency and to improve economic well being. With increased access to energy and environmental technologies, developing economies in the APEC region may be able to 'leap frog' today's energy devices and infrastructure by adopting more advanced technologies.

While concern for the local, regional and global environment is a major driver of the uptake of advanced technologies; there may be other implications of technology development for the APEC energy sector. Many APEC economies rely on imports of primary energy supplies, particularly oil, to meet energy needs and, as consumption grows over time, much of this demand will need to be met with imports. Several LNG importing economies, such as Korea, rely almost exclusively on LNG imports to supply their gas requirements for electricity generation. These economies may become even more import dependent as demand for electricity increases.

Technologies that reduce growth in energy consumption in APEC economies, and potentially reduce dependence on energy imports, could have important consequences for the security of energy supplies in APEC. Energy security is an ongoing challenge and APEC ministers recently reaffirmed their economies' commitment to use energy more efficiently, expand energy choices and capitalise on technological innovation as measures to address this challenge (APEC 2004a).

Objectives

The objectives in this study are to assess the current status of energy technologies in the electricity and iron and steel sectors in APEC economies and to analyse alternative scenarios of the future development and adoption of new energy and environmental technologies in these sectors. The focus of the study is examining the role that advanced technologies might play in reducing future growth in energy consumption and greenhouse gas emissions in the APEC region. For the purposes of this report, there are no direct linkages between the role of advanced technologies and current or potential climate change policy initiatives, such as the implementation of a carbon tax.

The scope of the study is the development and adoption of supply side technologies over the period to 2030. As such, the study does not address the considerable potential for demand side measures such as electricity conservation to contribute to reducing the growth in APEC energy consumption and greenhouse gas emissions. The study is also restricted to energy and environmental technologies that are presently available, and those that are currently near commercial viability. Technologies such as hydrogen fuel cells are considered outside the scope of the research. This reflects the long lead time between initial investments in the development of new technologies and the availability of such technologies for commercial deployment. The technologies that exist today and those that are well advanced through the research and development 'pipeline' are those that are assumed to be available over the next few decades.

In the electricity sector, coal and gas are expected to remain the two major fuel sources for power generation until 2030. The energy and environmental technologies discussed are specific to these fuels as they provide the greatest potential to reduce growth in energy consumption and greenhouse gas emissions and other environmental pollutants. The focus in the electricity sector is technologies for power generation. Carbon capture and storage technologies are considered outside the scope of the report.

The electricity and iron and steel sectors are highlighted as priorities in the report because they are large energy consumers. The electricity generation sector accounts for 40 per cent of primary energy consumption in APEC and is forecast to grow on average by around 2.5 per cent a year over the medium to long term. This makes it not only the largest but also one of the fastest growing stationary energy sectors in the APEC region. Iron and steel production accounts for approximately 7 per cent of final energy use in APEC.

There are three broad components of the study. First, the current status of energy and environmental technologies and existing trends in investment and innovation in new energy technologies are examined. A critical aspect of the study is to ensure that the diversity of issues and trends across all APEC economies is accommodated. For example, the development of more energy efficient steel making processes means that emerging steel industries, such as those in Malaysia and Thailand, may be based on a fundamentally different mix of primary fuels, achieving a significantly lower greenhouse gas emissions signature than in economies with older established steel making sectors. For this reason, six focus economies have been selected for which detailed information and data are presented on current and future investment in energy and environmental technologies.

The six focus economies are Australia, the People's Republic of China, the Republic of Korea, Mexico, Thailand and the United States. These economies have been selected to ensure geographic diversity across the APEC region as well as to represent economies at different levels of development and with different energy structures. China and the United States are included because they are both world leaders: China as an emerging economy that will lead demand for new technology in the 21st century; and the United States as a principal source of new energy and environmental technology and as a leader in the adoption of new technology. Korea represents the dynamic, newly industrialised economies where energy and environmental technologies are potentially important drivers of both productivity improvements and environmentally sustainable growth. Mexico and Thailand are included because of their geographic location and their varying degrees of economic development. Mexico is also an important energy exporter. Australia represents a smaller, mature, developed economy with an electricity sector highly dependent on coal.

In the second component of the study, the key drivers and impediments to both the development of new technologies and the dispersion and uptake of new technologies are examined. The future prospects of key technologies in the electricity and steel making sectors are assessed by identifying the main factors that drive the commercialisation of new technologies, and examining the main factors influencing the dispersion of new technologies both, within and between APEC economies.

Third, an analysis of the economic and environmental impacts of alternative scenarios of technology development and uptake of new technology is undertaken for all APEC economies using ABARE's global trade and environment model (GTEM). The modeling component of the research has two parts. This includes the development of a reference case in which the development, dispersion and uptake of existing, new and emerging technologies reflect underlying or 'business as usual' trends across APEC. Subsequently, a number of alternative scenarios are modeled to assess the economywide and energy sector impacts of alternative assumptions about more rapid development, dispersion and uptake of new technologies.

Structure of the report

An overview of the energy sector in APEC is presented in chapter 2. In chapters 3 and 4, the current status of technology and trends in investment and innovation in the electricity and iron and steel sectors, respectively, are discussed. An overview of technologies in all APEC economies is complemented by a more detailed discussion of technology trends in the six focus economies. Chapter 5 presents a discussion of the drivers and impediments to technology development and uptake. Chapter 6 includes a description of GTEM and how the model is used to assess the impacts of alternative scenarios of technology uptake in the electricity and steel making sectors. Results from the alternative technology simulations are presented in chapter 7, while the policy implications of alternative rates of technology uptake for APEC economies are discussed in chapter 8.

2

overview of the energy sector in APEC

- In parallel with strong economic performance, rapid industrialisation and rising personal incomes, energy consumption in the APEC region has grown by more than 50 per cent since 1980.
- Rising demand for electricity, in particular, and primarily in low income member economies, has provided the main catalyst for rising energy consumption in the region.
- Most APEC economies are highly reliant on fossil fuels for electricity generation — a characteristic that is likely to continue in the medium to longer term, and one that has implications for achieving environmental objectives both at a local and global level.
- Growing awareness of the environmental impacts of energy use, as well as other policy priorities such as the security of energy supply, can be expected to provide strong drivers for the development and uptake of advanced technologies in energy related sectors.

Energy consumption in the APEC region has grown strongly since 1980, underpinned by robust economic performance, rapid industrialisation and the growing demand for energy services generated by rising per person incomes. This growth has placed APEC at the centre of world energy markets, where it now accounts for around 60 per cent of total primary energy consumption.

Growth in APEC energy consumption has been driven to a large extent by the developing member economies. In these economies, rapid economic and population growth, together with industrial expansion, urbanisation and the transition from noncommercial biomass to commercial energy sources have been key factors underlying energy consumption patterns.

The most rapidly growing component of energy consumption has been the demand for electricity by the industrial, commercial and residential sectors. While the mix of fuels used to generate electricity varies significantly across APEC economies, coal has remained the primary energy source over the past twenty years, with a share of around 45 per cent in 2002.

Increasing energy consumption and heavy reliance on fossil fuels for power generation is expected to continue in the majority of APEC economies over the medium to longer term — a trend that will have implications for the environment, both at the local level and on a global scale. Against this background, technology designed to increase the efficiency of energy use offers a valuable option for enhancing the environmental performance of energy related activities in APEC member economies.

With electricity generation accounting for more than 40 per cent of carbon dioxide emissions from fuel combustion in the APEC region and also representing a major source of air pollutants such as nitrogen oxides, sulfur dioxide and particulates, there is likely to be significant value in adopting energy efficient technologies in this sector. Such technologies are a direct means of reducing greenhouse gas emissions and pollutants from electricity generation by lowering fuel consumption per unit of electricity output.

While environmental factors play a major role as a driver for the development and uptake of new technologies in energy related sectors, there are other important factors that can be expected to affect technology choices. One key consideration in a number of APEC economies is the security of energy supply. While the APEC region accounts for 53 per cent of world energy production and major energy producers in the region tend to be major energy exporters, APEC as a whole is a net importer of energy. Within APEC, there are several middle and high income economies that rely on imports for more than 80 per cent of their energy requirements. These include Japan, Korea and Chinese Taipei. In these cases, the adoption of energy efficient technologies could provide a key opportunity for enhancing the security of energy supply. With rising oil imports in recent years, technological innovation in China is also driven, in part, by the need to ensure adequate energy supplies and improve environmental quality while maintaining high levels of economic growth.

Primary energy consumption

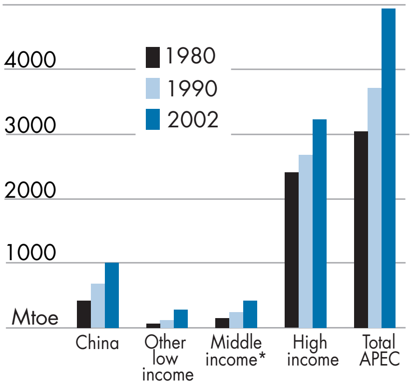
Reflecting the diversity of APEC member economies in terms of economic development, resource endowments, population growth and economic policy settings, growth in primary energy consumption has varied in intensity across the region (table 1). Total primary energy consumption (TPEC) in APEC has increased by almost 50 per cent since 1980 to reach more than 5 billion tonnes of oil equivalent in 2002, the latest year for which comprehensive data are available (figure 1). This figure excludes non-commercial biomass, used primarily in developing APEC economies, and

1 Key energy and economic indicators, 2002 a

	Gross domestic product per person	Energy consumption	Population	Energy intensity	Energy consumption per person
	US$'000	Mtoe	million	toe/US$'000	toe
Low income economies					
Papua New Guinea **b**	0.8	1.1	4.7	0.3	0.2
Viet Nam	2.2	19.4	80.4	0.11	0.5
Indonesia	3.2	113.3	211.7	0.17	0.7
Philippines, Rep. of	4.2	32.0	79.9	0.10	0.5
China, People's Rep. of	4.5	1 011.1	1 280.4	0.18	1.0
Peru	4.8	9.7	26.7	0.39	1.9
Thailand	6.7	69.6	61.6	0.17	1.4
Middle income economies					
Russian Federation	8.3	610.9	144.1	0.51	4.3
Mexico	8.9	149.2	100.4	0.17	1.6
Malaysia	9.1	49.3	24.3	0.22	2.1
Chile	9.7	20.4	15.6	0.13	1.6
Brunei Darussalam	14.7	2.1	0.4	0.36	6.1
Korea, Rep. of	16.9	200.6	47.6	0.25	4.3
High income economies					
New Zealand	20.4	16.8	4.0	0.21	4.5
Chinese Taipei	22.8	93.6	22.5	0.18	4.2
Singapore	23.5	25.3	4.2	0.26	6.1
Hong Kong, China	26.7	16.3	6.8	0.09	2.4
Japan	26.7	509.8	127.4	0.15	4.1
Australia	27.0	105.7	19.8	0.20	5.7
Canada	30.2	238.7	31.4	0.25	8.0
United States	35.4	2 221.5	287.5	0.22	8.0

a In this study, APEC economies are classified into three groups depending on their income levels. Low income economies are defined as those with a GDP per person in 2002 of US$7000 or less; middle income economies, US$7001–17 000; high income economies, US$17 001 or more. China is treated separately from other low income economies. In some cases, the Russian Federation is treated separately from other middle income economies because of lack of data availability prior to 1992. **b** Figures for Papua New Guinea are for 1999.
Sources: IEA (2004a); APERC (2002); IMF (2004).

1 Total primary energy consumption in APEC



*Excluding the Russian Federation

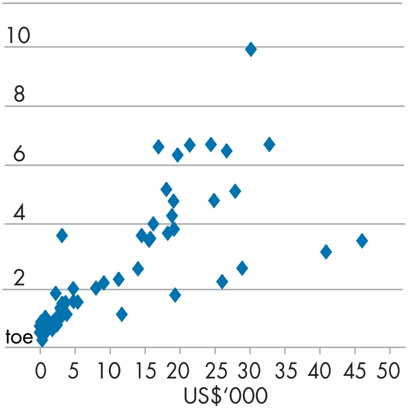
accounting for less than 8 per cent of total primary energy used in the region. Energy consumption growth was strongest in the rapidly expanding low income economies where an increase in income has led to a more than proportionate increase in energy consumption. In this group, China has led the growth in primary energy consumption, accounting for 35 per cent of the total incremental growth in the APEC region between 1980 and 2002. Energy consumption in economies in south east Asia such as Thailand has grown more rapidly than elsewhere in the region, averaging more than 5 per cent a year over that period.

Middle income economies with economic structures highly geared toward energy intensive industries have also sustained relatively high growth rates in their primary energy consumption over that period. Energy consumption in Korea, for example, has increased by more than 7 per cent a year over the past two decades, driven by strong economic growth and expansion in energy intensive industries. The Russian Federation is a major exception to the general trend characterising energy consumption in middle income economies over that period. Although no data are available for the period prior to 1992, primary energy consumption in the Russian Federation in 2002 was equivalent to 80 per cent of its level in 1992, reflecting the major economic upheavals in that economy in the early 1990s.

In broad terms, energy consumption growth has been moderate in high income economies, with average annual growth of 1.3 per cent between 1980 and 2002. Sectoral shifts toward less energy intensive industries and the adoption of more energy efficient technologies have contributed to a lower level of energy intensity in these economies over time.

In parallel with trends in total primary energy consumption, energy consumption per person in APEC has increased in the past twenty years to reach an average of 2.2 tonnes of oil equivalent in 2002. While this general upward trend is evident across the majority of member economies, the range in energy consumption per person varies widely across the region from 0.2 tonnes of oil equivalent in Papua New Guinea to 8 tonnes of oil equivalent in Canada and the United States (table 1). In general, at low income levels, rising incomes are strongly linked to an increase in the demand for commercial and more convenient energy sources, and improved access to energy services such as transport (figure 2). However, at higher income levels, the demand for energy tends to level off as energy requirements approach saturation point.

2 Per person GDP and energy consumption in APEC, 1980–2002

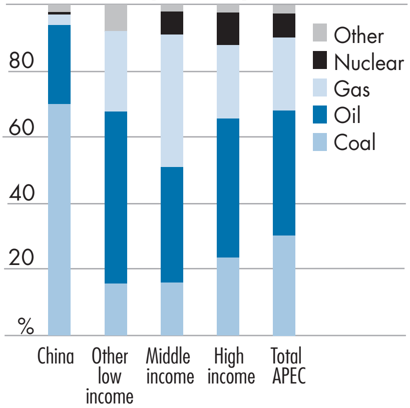


Energy intensity, measured as total primary energy consumption per unit of gross domestic product, has declined in the APEC region as a whole over the past two decades. This improvement has been driven primarily by high income economies where the shift to services and the introduction of energy efficient technologies have led to less energy intensive economic structures. The fall in energy intensities in developed economies has been offset to some extent by an increase in energy intensities in a number of low income economies. Key factors underlying the trend in developing economies include the shift from labor intensive to capital intensive production structures and limited access to energy efficient technologies.

Fossil fuels (coal, oil and natural gas) account for 90 per cent of total primary energy consumption in APEC. Oil has remained the dominant fuel since 1980. Nonetheless, oil's share of the primary energy mix fell from 48 per cent to 38 per cent between 1980 and 2002, largely as a result of energy supply diversification strategies throughout the region designed to address energy security concerns.

In contrast, the shares of coal and natural gas in primary energy consumption have increased over the period since 1980. Expansion in natural gas consumption has been particularly strong, with average annual growth of 3 per cent over that period. In 2002, coal and gas accounted for 30 per cent and 22 per cent of the region's primary energy consumption respectively.

3 **Total primary energy consumption, by fuel, 2002**



From a regional perspective, the primary energy mix is quite diverse across APEC member economies (figure 3). Oil is the major fuel used in low income economies, excluding China, where there are substantial oil reserves and highly oil dependent industrial structures. Oil is also the main fuel in the primary energy mix of high income economies, with a share of 42 per cent in 2002. The bulk of oil consumption in industrialised economies is accounted for by the road transport sector.

Coal also features prominently in the energy consumption profile of APEC economies. China is the largest coal consumer and producer in the APEC region, with coal accounting for 70 per cent of primary energy consumption in 2002. Coal has continued to play a central role in China's energy system since the early 1980s, largely because of coal's competitiveness relative to other fuels, and its ready availability. In most other APEC economies, coal accounts for a third or less of total primary energy consumption. The electricity sector is the key driver of coal consumption throughout APEC economies.

The role played by natural gas has expanded significantly across a wide spectrum of APEC economies since the 1980s. The importance of natural gas in the energy mix is most remarkable in low and middle income economies endowed with abundant gas reserves. For example, gas accounts for 29 per cent of total primary energy consumption in Indonesia and 53 per cent in the Russian Federation. However, the highest growth rates in gas consumption have occurred since 1990 in economies such as Korea and Chinese Taipei where high energy import dependence has increased the premium on a diversified energy mix.

Growth in gas consumption in high income economies such as the United States has also been strong, driven partly by energy market reform initiatives that have enhanced the competitiveness of gas relative to other fuels and promoted the development of gas supply infrastructure and partly by growing environmental concerns.

There are eight economies in APEC that have significant nuclear power programs. These are Canada, China, Japan, Korea, Mexico, the Russian Federation, Chinese Taipei and the United States. Nuclear power capacity in these economies has remained relatively stable since the early 1990s and nuclear power represents only 7 per cent of primary energy consumption across the APEC region. Safety issues and economic factors have led several economies to re-evaluate their policies affecting investment in nuclear power generation plants. While these factors have also been considered in Japan and Korea, energy security considerations arising from limited indigenous energy resources have provided the rationale for an increase in nuclear power generation capacity in these economies over the past decade.

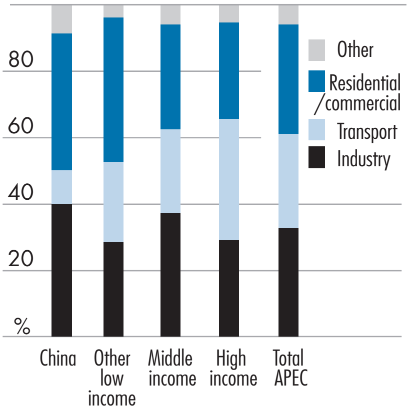
Hydropower and commercial renewable energy jointly account for only 3 per cent of primary energy consumption in the APEC region. The share of hydropower in the APEC primary energy mix has stagnated over much of the past twenty years, largely as a result of mounting environmental concerns surrounding the development of large scale projects. However, it remains the principal form of electricity generation in Canada and New Zealand where hydropower resources are relatively abundant. While the demand for commercial nonhydro renewables has increased from a very low base in recent years and in response to environmental considerations, particularly in high income economies, they still account for only a marginal share of primary energy consumption in APEC economies.

Final energy consumption

Total final energy consumption (TFEC) is defined as the total amount of energy used by final consumers. It includes energy used by industry, transport, household and commercial services sectors but does not include the energy used in transformation (principally electricity generation and petroleum refining), and transmission and distribution activities. TFEC can include both primary and secondary fuels.

Over the past twenty years, the sectoral composition of energy consumption in the APEC region has evolved with rising personal incomes, shifts in economic structures and new technologies. For APEC economies as a whole, the transport sector has been the fastest growing end use sector since 1980. In 2002, the transport sector consumed 28 per cent of total final energy in the region. The growth in the transport sector has been particularly strong in low income economies where economic growth and urbanisation are

4 **Total energy consumption in APEC, by end use, 2002**



associated with a higher demand for both passenger and freight transport services. In China, for example, energy consumption by the transport sector increased by 7 per cent annually between 1990 and 2002, driven by the increase in the demand for freight transport and rising vehicle ownership.

Despite the rapid expansion of the transport sector, the industry sector and the residential and commercial sectors are the leading consumers of energy in APEC, each accounting for 33 per cent of total final energy consumption in 2002 (figure 4). High income economies account for half of the industry sector's share of energy consumption in APEC — a contribution that has remained largely unchanged since 1980. Over that period, the growth in industry sector energy demand in high income economies has been partially offset by the transition from heavy to more service oriented industries, and by the adoption of more energy efficient technologies.

Growth in industrial energy consumption has been more vigorous in middle and low income economies. As a group, middle income economies (excluding the Russian Federation) have more than doubled their industrial energy consumption between 1980 and 2002. Korea and Malaysia, in particular, have sustained annual growth rates of around 7 per cent over that period in line with the expansion of energy intensive industries. In comparison, industrial energy consumption in low income economies has increased threefold since 1980. Economies such as Thailand and Indonesia highlight trends that are representative of developing economies as they shift from agriculture and other labor intensive sectors to manufacturing industries.

The energy intensive iron and steel industry is a key component of industrial energy demand in the APEC region, accounting for 7 per cent of final energy consumption in 2002. China accounts for more than 40 per cent of energy consumed by the iron and steel industry in the region, followed by the Russian Federation and the United States. Final energy consumption in the iron and steel industry has fallen on average in major producing high income economies such as the United States and Japan over the period since 1980. This reflects, in part, the relatively flat demand by steel intensive industries and, in part, the deployment of energy efficient steel making technologies. In comparison, energy consumed by the iron and steel industry has increased significantly in economies such as China, Korea and Chinese Taipei over the past two decades in line with rising incomes and spending on infrastructure as well as strong export demand.

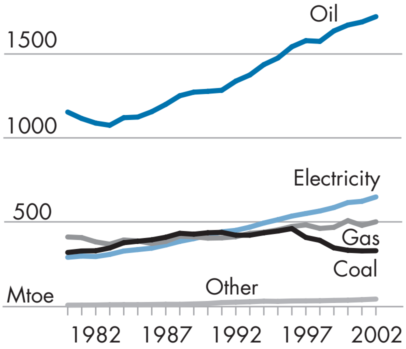
The residential and commercial sector is also an important contributor to final energy consumption in the APEC region. Its share of aggregate energy consumption in end use sectors ranges from 29 per cent in high income economies to 41 per cent in low income economies. Paralleling the trend in total energy consumption, growth in residential and commercial sector energy consumption over the past twenty years has been stronger in economies in the low and middle income group. Nonetheless, there is still wide variation in per person energy consumption in the residential and commercial sector across APEC member economies. Differences in income levels, the degree of urbanisation and rural electrification, and climatic factors are the key determinants of energy demand at the residential and commercial level.

Electricity

Electricity has been the fastest growing fuel used in the final energy mix across all APEC economies since 1980, expanding at an average annual rate of 4 per cent over that period (figure 5). Electricity use has expanded most rapidly in low income economies, by an average of 8 per cent a year. China alone accounts for more than 80 per cent of the incremental growth in electricity consumption in low income economies. This is equal to approximately a quarter of APEC's total increase in electricity consumption over the period 1980–2002.

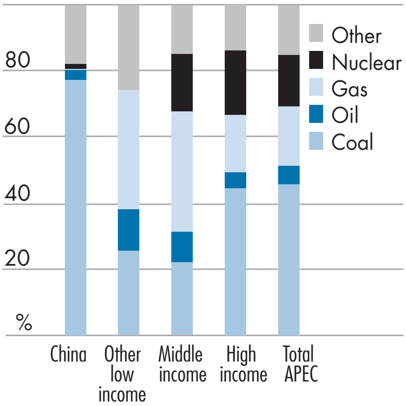
5 Final energy consumption in APEC, by fuel

Excluding the Russian Federation



Coal is the major fuel for electricity generation in APEC, accounting for 46 per cent of the total in 2002, followed

6 Electricity generation in APEC, by fuel, 2002



by natural gas (18 per cent), nuclear (16 per cent), hydropower (14 per cent) and oil (6 per cent). Again, however, the fuel mix varies considerably across economies (figure 6).

Coal accounts for the largest share of power generation in high income economies (44 per cent), largely because of its competitiveness relative to other fuels. However, in many of these economies the importance of natural gas as a fuel for power generation has risen significantly over the past decade to account for 17 per cent of total electricity output in the high income group in 2002. Within this group, nuclear accounts for a high proportion of power generation in Japan, Chinese Taipei and the United States.

Coal also dominates the power generation fuel mix in China, contributing to more than 78 per cent of electricity output in 2002. Coal has maintained this position throughout the 1980s and 1990s, primarily because of China's access to abundant coal reserves. As a relatively low cost fuel, coal has played a fundamental role in enabling China to sustain rapid and energy intensive economic growth over that period.

So far, natural gas has played a more prominent role in the electricity fuel mix of other developing economies than it has in China. This is clearly the case in Indonesia and Thailand where gas accounts for 72 per cent and 22 per cent of electricity output respectively.

The middle income economies as a group are also reliant on natural gas in their power sectors. The share of gas fired electricity is particularly high in Malaysia, Mexico and the Russian Federation — economies endowed with substantial gas resources. Regulations on carbon dioxide emissions and reform of the gas sector have also contributed to the expansion of natural gas in Mexico's electricity industry in recent years. While gas has a lower profile in other middle income economies, it has made significant inroads in the electricity sector in Korea, for example, since the introduction of liquefied natural gas (LNG) imports in 1986.

Oil contributes only a minor share of the electricity generation fuel mix across all income groups within the APEC region. Oil's share has fallen significantly over the past two decades, principally reflecting concerns about rising oil import dependence and the security of energy supply.

Environmental implications of energy consumption

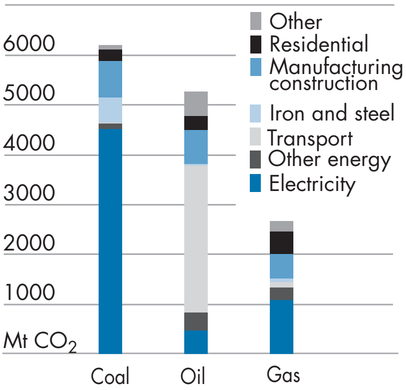
The significant increase in energy consumption in the APEC region since 1980 has been accompanied by a growing awareness of the environmental impacts of energy use, both at the local and global levels. In a local context, the control of energy related greenhouse gas emissions of sulfur dioxide, a pollutant known to contribute to the problem of acid rain and eutrophication of soils and water, is considered a priority across a number of APEC economies. Local environmental issues associated with energy use also include the adverse impacts of fuel combustion on air quality. Emissions of nitrogen oxides and particulates associated with electricity generation present a major challenge in improving air quality standards, particularly in low income economies with high rates of industrialisation and lenient environmental controls.

At the global level, widespread concerns about the adverse impact of human induced climate change have been widely recognised as a significant issue requiring an internationally coordinated response. Fossil fuel combustion is the major source of greenhouse gas emissions generated by human activity (anthropogenic emissions). Coal accounts for a large share of anthropogenic carbon dioxide emissions as it is the most carbon intensive fuel.

In conjunction with growth in energy demand and the continued reliance on fossil fuels, carbon dioxide emissions from fossil fuel combustion have increased by more than 70 per cent in the APEC region since 1980 to reach 14 billion tonnes in 2001 (60 per cent of global carbon dioxide emissions from fossil fuel combustion). Over that time, the largest emitters of greenhouse emissions have been the high income economies. As a group, they represented 57 per cent of APEC's energy related carbon dioxide emissions in 2001. Low income economies, including China, produced 26 per cent of the region's greenhouse gas emissions in that year. China is the single largest emitter of carbon dioxide emissions in the low income group, with 22 per cent of total carbon dioxide emissions in the APEC region.

On a fuel basis, coal combustion accounted for 54 per cent of the growth in energy related carbon dioxide emissions between 1980 and 2001, followed

7 **Carbon dioxide emissions in APEC, by fuel and sector, 2001**



by oil and gas (23 per cent each). Coal’s share of total regional carbon dioxide emissions was 44 per cent in 2001.

Electricity generation, a sector highly dependent on fossil fuels, has been a growing source of carbon dioxide emissions in the APEC region. It contributed to the bulk of carbon dioxide emissions in 2001, with a share of 43 per cent (figure 7; APERC 2002). The transport and industrial sectors are also highly emissions intensive sectors, accounting for 22 per cent and 18 per cent respectively of total carbon dioxide emissions. In conjunction with the substantial increase in the demand for transport services, particularly in low income APEC economies, carbon dioxide emissions from the transport sector have also risen significantly over the past twenty years. Heavy reliance on oil, combined with limited fuel substitution possibilities contribute to the high carbon intensity of transport sectors in the region.

Compared with the transport sector, carbon dioxide emissions from the manufacturing sector are generated by a wider range of fuels. However, within that sector, coal plays a major role in key energy intensive industries such as steel making. In 2001, the iron and steel sector represented more than 40 per cent of coal based industrial carbon dioxide emissions in the APEC region. China, as the world’s leading iron and steel producer, accounted for more than 60 per cent of these carbon dioxide emissions. This reflects not only the size of China’s iron and steel industry but also its high energy intensity compared with that of other major producing economies such as Japan and the United States.

Other things being equal, the projected growth in APEC energy consumption can be expected to lead to a significant increase in greenhouse gas emissions from the region over the period to 2020. Primary energy consumption in APEC is expected to continue to increase steadily, at 2.2 per cent a year over the period to 2020 (APERC 2002). In absolute terms, the largest expansion is projected to occur in China and the United States. However, energy consumption will grow most rapidly in percentage terms in low and middle income economies, mainly in Asia. This is highlighted by economies such as Malaysia, Thailand and Viet Nam, all of which are projected to increase their primary energy use by approximately 4 per cent over the period to 2020. These projections are driven by relatively strong economic growth, expanding population and expanding demand in the transport and services sectors.

A key factor underlying the projected growth in energy consumption in the APEC region is the expansion of energy intensive industries, primarily in low and middle income economies. Energy consumption in China's industrial sector, for example, is expected to grow by 2.7 a year to account for 28 per cent of total industrial energy consumption in APEC in 2020. A major part of this growth is underpinned by the expansion of key industries such as iron and steel, and chemicals. Expansion in the steel industry can be expected to lead to a higher demand for electricity over that period (APERC 2002).

Over the medium to longer term, energy consumption in APEC economies is one area where fossil fuels are likely to continue to play a major role. Coal will feature strongly in the electricity generation fuel mix in low and middle income economies in Asia, and account for a large percentage of their growth in greenhouse gas emissions over the period to 2020. Further, the sharp increase in vehicle ownership and freight transport projected for these economies is also expected to have a significant impact on regional and global emission levels over that period.

Based on APERC (2002) estimates, greenhouse gas emissions (including carbon dioxide, methane and nitrogen oxides) from fossil fuel combustion in the APEC region will increase by around 60 per cent to reach 22 billion tonnes of carbon dioxide equivalent in 2020. The power generation sector, followed by the transport and industrial sectors, will continue to be the key contributors to the growth in emissions over the outlook period.

Projections of energy consumption and greenhouse gas emissions for the APEC region are presented in chapter 6.

3

technology characteristics of the electricity sector in APEC

- Differences in resource endowments, economic structures and government policy settings underpin the diverse pattern of technology adoption in the electricity sector across APEC economies.

- Generally, economies with limited indigenous resources have adopted more efficient coal or gas fired power generation technologies, supplemented by non fossil fuel fired technologies, including nuclear power and hydropower.

- Across APEC, coal is the dominant fuel for power generation. Coal is also the most carbon intensive fossil fuel and the main technology choice, subcritical pulverised coal, is relatively inefficient compared with more advanced coal technologies such as supercritical and ultra supercritical pulverised coal.

- Given the relatively low average thermal efficiencies of fossil fuel fired electricity generation plants in the APEC region, and the need for considerable generation capacity expansion in many economies, there is significant scope for narrowing the gap between current and best practice technologies when refurbishing existing capacity or building new plant.

- Reflecting a broader regional trend, governments in the focus economies in this report are adopting a range of policy initiatives designed to foster the development and uptake of more efficient coal and gas fired power generation technologies, while also aiming to increase the role played by renewable energy sources.

Many factors influence the choice of technology in energy intensive sectors, such as the electricity sector. These include economic factors such as capital and operating costs, including fuel costs; government policy, including the nature of environmental regulations and standards; available indigenous energy reserves; and energy security objectives. The degree of deregulation in an energy sector can also be an important determinant of technology choice.

The degree of market power of incumbent participants may also affect technology choices, as will laws governing intellectual property. Technology choices can also be influenced by government requirements to favor indigenous fuels or domestic manufacturers (IEA 1999).

These factors, coupled with the enormous diversity that exists between APEC member economies in terms of economic development and resource endowments, have wide ranging implications for the pattern of energy consumption and production, as well as the development, transfer and adoption of energy technologies in the region. As discussed in the previous chapter, in economies richly endowed with coal resources such as Australia and China, coal fired power generation technologies dominate the electricity sector. Conversely, economies heavily reliant on imports of fossil fuels, including Japan and Korea, often use nuclear power generation technologies, or more efficient natural gas fired technologies.

The objective in this chapter is to examine the current status of energy and environmental technologies, as well as trends in investment and innovation in the electricity generation sector in the APEC region generally, with particular emphasis on the six focus economies. The key characteristics of the existing capital stock, such as fuel and technology shares, and proposed capacity additions are presented subject to data availability. Given the diversity across APEC economies, discussion of these characteristics provides an indication of the range of thermal efficiencies in the region and, hence, the potential for technology adoption to reduce the growth in energy consumption and associated environmental impacts in APEC economies.

Technology in the electricity generation sector in APEC

The focus of this discussion is thermal power technologies that involve the combustion or gasification of coal, oil or natural gas to drive a turbine that is connected to an electricity generator. A description of the technologies considered in this report and their thermal efficiencies and power generation costs is provided in appendix A.

Considerable reductions in electricity consumption may be achieved through demand side management initiatives that are designed to encourage consumers to modify their level and pattern of electricity use. While these initiatives may be a factor driving the rate of demand growth for electricity and, hence, the rate of change in supply side infrastructure, their effect on supply side technology uptake is beyond the scope of this report. Assumptions underlying growth in demand for electricity are presented in chapter 6.

Between now and 2030, power companies in APEC will build, retrofit or refurbish numerous power generation plants to satisfy rising electricity demand as well as meet current or proposed environmental standards. The menu of electricity generation technologies from which producers will choose can be broadly classified into conventional and advanced technologies.

‘Conventional technologies’ are ‘mature’ in that they are currently well used worldwide, with known economic and environmental performance. Conventional technologies include internal combustion engines, stoker and stoker cyclones, pulverised coal (PC), atmospheric fluidised bed combustion (FBC), and natural gas combined cycle (NGCC). While these technologies are well established, advances in some aspects of the technology will continue to bring efficiency improvements. For example, early PC technology operated at lower, or subcritical, steam pressure and temperature, with a correspondingly lower thermal efficiency than supercritical PC power generation plants that have been developed more recently.

Supercritical steam temperature and pressure technology has now become the standard for new PC power generation plants in many parts of the world and ultra supercritical PC, a further efficiency development, is now considered an advanced technology. Similarly, atmospheric FBC technology is well established but some aspects of the technology are being advanced to further improve efficiencies and reduce greenhouse gas emissions (see pressurised fluidised bed combustion in appendix A).

‘Advanced technologies’ encompass a range of technologies that have been, or are being, developed, with an emphasis on reducing emissions of greenhouse and other gases and particulates. Typically, advanced technologies are not yet proven at a commercial scale. Much of the research into advanced technologies is focused on developing ‘cleaner coal’ technologies aimed at reducing carbon emissions from coal fired power generation plants through improvements in thermal efficiency. The main clean coal technologies are ultra supercritical pulverised coal, pressurised fluidised bed combustion, ultra clean coal and integrated gasification combined cycle.

To a significant extent, technology development in the electricity generation sector is designed to enhance the thermal efficiency of power generation plants. The thermal efficiency of a power generation plant is the rate at which fuel is converted to electricity. The thermal efficiency of a power station is mainly determined by fuel type and quality, the efficiency of the turbine, the boiler efficiency and the station auxiliary energy use — for example, the energy consumed in post combustion emission control technology.

Improvements in the thermal efficiency of power generation plant offer one of the most significant options for reducing fuel consumption and emissions of greenhouse gases and other pollutants. For example, the average thermal efficiency of subcritical PC fired power generation in developed economies is around 35 per cent. An increase in efficiency to 50 per cent represents a reduction in carbon dioxide emissions of approximately 30 per cent compared with a power generation plant operating at 35 per cent efficiency. Improvements in the efficiency of gas fired power generation plant can also lead to significant reductions in fuel consumption and carbon dioxide emissions. Reductions of up to 50 per cent are possible if the thermal efficiency of NGCC power generation plants improved from 40 to 75 per cent (DTI 2004).

This has implications for fuel consumption and global emissions of greenhouse gases considering the existing capital structure of power generation technologies across the APEC region. The factors that influence technology decisions are different across APEC and this has led to diversity in the pattern of technology development, transfer and adoption. Supercritical pulverised coal technology, for example, accounts for a large share of coal fired power generation capacity in Japan, an economy that has been instrumental in developing technological improvements in coal fired power generation (table 2). On the other hand, economies such as Indonesia and Thailand have a large proportion of NGCC technology, in part reflecting the indigenous resource endowments of these economies.

Subcritical PC technology dominates the power generation sector, accounting for more than a quarter of capacity from all sources in the APEC region in 2001. This translates to around three quarters of coal fired power generating capacity in the region. Typically, this technology has relatively low conversion efficiencies compared with other coal and gas technologies. In addition, the variation in the average thermal efficiency of subcritical

2 APEC electricity generation capacity, 2001

		Australia	Brunei Darussalam	Canada	Chile	China	Hong Kong, China
Total capacity for all energy sources	MW	44 526	818	110 601	9 700	231 038	11 041
Gas fired capacity	MW	5 989	806	9 991	1 713	1 231	2 046
Gas fired share of total MW	%	13.4	98.5	9.0	17.7	0.5	18.5
Combined cycle or combined heat and power	% gas	17.7	0.0	22.7	98.6	40.4	100.0
Simple cycle gas turbine [a]	% gas	41.8	100.0	24.3	0.3	58.1	0
Simple cycle steam turbine							
– subcritical	% gas	40.5	0.0	53.1	1.1	1.5	0
– supercritical	% gas	0	0	0	0	0	0
Oil fired capacity	MW	2 733	12	4 684	1304	13 767	2 382
Oil fired share of total MW	%	6.1	1.5	4.2	13.4	6.0	21.6
Combined cycle or combined heat and power	% oil	1.0	0	3.3	8.4	21.7	0
Simple cycle [a]	% oil	77.3	100.0	29.3	74.7	43.0	55.1
Simple cycle steam turbine							
– subcritical	% oil	21.6	0	67.3	16.9	35.4	44.9
– supercritical	% oil	0	0	0	0	0	0
Coal fired capacity	MW	27 057	0	17 818	1 947	160 413	6 610
Coal fired share of total MW	%	60.8	0	16.1	20.1	69.4	59.9
Stoker cyclone	% coal	0.2	0	0	2.8	0.7	0
Pulverised coal steam turbine							
– subcritical	% coal	99.8	0	99.1	93.7	95.4	100.0
– supercritical	% coal	0	0	0	0	3.3	0
Fluidised bed	% coal	0	0	0.9	3.5	0.6	0
Non fossil fuel power generation	MW	8 751	0	78 108	4 735	55 627	4
Non fossil fired share of total MW	%	19.7	0	70.6	48.8	24.1	0

continued

2 APEC electricity generation capacity, 2001 *continued*

		Indonesia	Japan	Korea, Rep. of	Malaysia	Mexico	New Zealand
Total capacity for all energy sources	MW	30 041	256 268	53 057	17 209	39 352	9 269
Gas fired capacity	MW	5 690	52 858	11 910	7 837	4 872	1 592
Gas fired share of total MW	%	18.9	20.6	22.4	45.5	12.4	17.2
Combined cycle or combined heat and power	% gas	69.3	41.9	59.2	45.6	48.3	61.8
Simple cycle gas turbine [a]	% gas	30.4	1.8	5.9	49.8	29.6	0.4
Simple cycle steam turbine							
– subcritical	% gas	0.3	14.0	34.9	4.6	22.0	37.8
– supercritical	% gas	0	42.3	0	0	0	0
Oil fired capacity	MW	9 467	71 667	6 298	3 585	17 850	433
Oil fired share of total MW	%	31.5	28.0	11.9	20.8	45.4	4.7
Combined cycle or combined heat and power	% oil	20.9	4.3	29.9	20.7	2.0	3.7
Simple cycle [a]	% oil	51.8	4.8	27.2	37.3	13.1	96.3
Simple cycle steam turbine							
– subcritical	% oil	27.2	52.7	42.9	42.0	84.9	0
– supercritical	% oil	0	38.3	0	0	0	0
Coal fired capacity	MW	7 197	29 549	13 900	1 700	2 600	1 021
Coal fired share of total MW	%	24.0	11.5	26.2	9.9	6.6	11.0
Stoker cyclone	% coal	1.0	0	0.2	0	0	0
Pulverised coal steam turbine							
– subcritical	% coal	99.0	34.1	37.7	100.0	100.0	99.2
– supercritical	% coal		62.9	58.5	0	0	0
Fluidised bed	% coal	0	2.9	3.7	0	0	0.8
Non fossil fuel power generation	MW	7 686	102 193	20 951	4 087	14 029	6 222
Non fossil fired share of total MW	%	25.6	39.9	39.5	23.8	35.7	67.1

continued

2 APEC electricity generation capacity, 2001 *continued*

		Papua New Guinea	Peru	Philippines	Russian Federation	Singapore
Total capacity for all energy sources	MW	780	4 863	17 385	217 256	7 115
Gas fired capacity	MW	121	222	683	87 946	1 299
Gas fired share of total MW	%	15.5	4.6	3.9	40.5	18.3
Combined cycle or combined heat and power	% gas	0	0	48.3	0.4	3.8
Simple cycle gas turbine **a**	% gas	100.0	94.3	51.7	2.3	0
Simple cycle steam turbine – subcritical	% gas	0	5.7	0	76.9	96.2
Simple cycle steam turbine – supercritical	% gas	0	0	0	20.3	0
Oil fired capacity	MW	438	1 719	7 862	11 706	5 331
Oil fired share of total MW	%	56.1	35.3	45.2	5.4	74.9
Combined cycle or combined heat and power	% oil	0	1.8	21.9	56.7	11.4
Simple cycle **a**	% oil	69.1	83.7	52.4	2.8	10.4
Simple cycle steam turbine – subcritical	% oil	30.9	14.6	25.7	26.8	78.2
– supercritical	% oil	0	0	0	13.7	0
Coal fired capacity	MW	0	270	4 258	50 782	0
Coal fired share of total MW	%	0	5.6	24.5	23.4	0
Stoker cyclone	% coal	0	0	0	6.3	0
Pulverised coal steam turbine – subcritical	% coal	0	100.0	100.0	78.3	0
– supercritical	% coal	0	0	0	15.5	0
Fluidised bed	% coal	0	0	0	0	0
Non fossil fuel power generation	MW	221	2 652	4 581	66 822	485
Non fossil fired share of total MW	%	28.4	54.5	26.4	30.8	6.8

continued

2 APEC electricity generation capacity, 2001 *continued*

		Chinese Taipei	Thailand	United States	Viet Nam	Total
Total capacity for all energy sources	MW	34 307	23 513	832 875	6 391	1 957 404
Gas fired capacity	MW	4 279	12 154	188 343	898	402 476
Gas fired share of total MW	%	12.5	51.7	22.6	14.1	20.6
Combined cycle or combined heat and power	% gas	82.6	58.8	25.0	0	26.4
Simple cycle gas turbine **a**	% gas	1.4	8.5	24.8	100.0	16.6
Simple cycle steam turbine						
– subcritical	% gas	16.0	32.8	37.1	0	40.9
– supercritical	% gas	0	0	13.1	0	16.1
Oil fired capacity	MW	7 970	1 142	79 202	1 506	251 058
Oil fired share of total MW	%	23.2	4.9	9.5	23.6	12.8
Combined cycle or combined heat and power	% oil	20.2	14.5	4.9	3.4	10.4
Simple cycle **a**	% oil	28.2	16.6	42.1	41.6	27.5
Simple cycle steam turbine						
– subcritical	% oil	51.6	68.9	52.3	55.0	50.4
– supercritical	% oil	0	0	0.7	0	11.8
Coal fired capacity	MW	9 218	3 467	333 528	693	672 029
Coal fired share of total MW	%	26.9	14.7	40.0	10.8	34.3
Stoker cyclone	% coal	0	0	8.7	6.9	5.0
Pulverised coal steam turbine						
– subcritical	% coal	100.0	80.2	65.6	93.1	75.8
– supercritical	% coal	0	0	24.2	0	17.9
Fluidised bed	% coal	0	19.8	1.5	0	1.2
Non fossil fuel power generation	MW	12 840	6 750	231 802	3 294	631 841
Non fossil fired share of total MW	%	37.4	28.7	27.8	51.5	32.3

a Includes internal combustion engines.
Source: APEC 2001.

pulverised coal across the APEC region was estimated to be between 27 and 38 per cent (APEC 2001). Similar observations can be drawn for gas fired capacity, which is also dominated by relatively inefficient technologies, particularly subcritical steam turbines, in many APEC economies.

Much of the discussion presented in this chapter is related to coal and natural gas, the dominant fossil fuels in power generation in APEC. Oil fired capacity is relatively small and declining as a share of the total as many economies continue to switch to other fuels in response to rising oil prices and import dependency concerns. A small number of economies including Mexico and Papua New Guinea have shares of oil fired capacity in excess of 40 per cent of total capacity. This is, in part, a consequence of being tied to existing technologies that were commissioned when oil prices were lower, or were constructed for a specific purpose such as electrification in remote locations. As oil is not projected to be a major fuel in the electricity generation sector over the coming decades or a key area for energy conservation or technological advancement, it is not likely to provide significant opportunities to reduce carbon dioxide emissions through improvements in thermal efficiency.

Electricity generation technologies in the focus economies

In line with the diversity evident across the APEC region, the focus economies in this study display a wide mix of electricity generation portfolios, reflecting different resource endowments, economic structures and policy priorities. These factors can be expected to continue to affect technology choices in the future. However, despite these differences, a clear trend is emerging across a wide spectrum of APEC economies — a gradual move toward more energy efficient technologies. The status of current technologies as well as future market, policy and technological directions for the electricity sector in the six focus economies are discussed below.

Australia

Australia is resource rich and has large reserves of coal and natural gas, much of which is exported along with other energy sources such as uranium. The Asia Pacific region is a major destination for Australian exports of natural gas and coal, and the share of exports to the region is expected to increase over the coming decades as it builds on a reputation as a reliable fuel supplier.

As in many other APEC economies, Australia has been moving toward a more competitive energy market and there have been significant market reforms, particularly in the electricity and gas markets, to enhance energy productivity and security, and resource development. There have also been a number of policy responses to environmental concerns, including assistance for the development of renewable energy sources and more energy efficient technology. In addition, joint industry and government research initiatives have been proposed to develop clean coal and carbon sequestration technologies as part of a national plan to reduce greenhouse gas emissions.

Current status of technology

Demand for electricity has increased steadily over the past decade, with annual growth of almost 3 per cent. Australia produced close to 220 TWh of electricity in 2002 (table 3). More than 85 per cent of output was from thermal sources.

Coal fired power generation plants are by far the dominant thermal power generation source, with oil and gas fired accounting for less than 10 per cent of output in 2001. Of coal fired power generation, around 70 per cent is from high quality black coal. Coal fired power generation plants provide

3 Electricity generation in Australia, 2002

Fuel	Output[a]	Average thermal efficiency[b]	Key technologies
	TWh	%	
Brown coal	57	28	PC – subcritical
Black coal	116	37	PC – subcritical
Oil	3.8	33	
Gas	26	35	Simple cycle / steam turbine – subcritical
Nuclear	0		
Hydro	16		
Other renewables	0.4		
Total output	219		
Total capacity (GW)	44.5		

a Sourced from IEA Energy Balance (2004a). **b** Average thermal efficiencies are in lower heat value terms (LHV) and are derived from Akmal et al. (2004).

much of the base load power generation capacity (APEC 2003; Akmal et al. 2004; ESAA 2002).

Despite investment in new generating capacity over the past five years, growth in demand for electricity has resulted in declining reserve margins in eastern Australia. Much of the increase in capacity in recent years has been in response to demand for peak load electricity. Australia had electricity generating capacity equal to 44.5 gigawatts in 2001. Approximately 60 per cent of this capacity was coal fired and almost 15 per cent gas fired, while 14 per cent was renewables, principally hydropower. Coal fired generating capacity is primarily located near abundant coal reserves. A small proportion of installed capacity is oil fired (APEC 2001; EIA 2002).

Almost all coal fired power generation plants are subcritical PC, although a FBC power generation plant with a capacity of 150 megawatts was brought online in 2001 (table 2). This power generation plant uses waste tailings from coal mining operations. There are three supercritical PC fired power generation plants, all in the northern state of Queensland, that have a total capacity in excess of 2000 megawatts (QDNRM 2004).

Simple cycle gas turbines and subcritical gas each account for about 40 per cent of installed gas fired capacity. There was approximately 2000 megawatts of installed NGCC in 2002, including those that incorporate cogeneration, and some of these power generation plants have planned expansions (APEC 2001; AGO 2004a).

The average thermal efficiency of Australia's subcritical coal fired power generation plants is behind that of world's current best practice. Most subcritical coal fired power generation capacity uses black coal and the most efficient of these have thermal efficiencies of 35 per cent (HHV) which, when compared with world's best practice of 37.7 per cent suggests there is some potential for improvement. Brown coal fired power generation plants operate at lower efficiencies of between 26 per cent and 32 per cent. The average efficiency of simple cycle gas turbines was between 25 and 35 per cent.

The thermal efficiency of both coal and gas fired power generation plant is expected to improve as newer power generation plant comes on line and older power generation plant is overhauled and upgraded (AGO 2000a; Coal21 2004).

Future directions for electricity generation

Electricity generation in Australia is expected to increase significantly over the next thirty years and, supported by abundant indigenous reserves and competitive prices, coal is likely to remain the dominant fuel. The share of coal in the electricity generation mix is, however, projected to decrease slightly to 2020. Growth in gas fired electricity generation is projected to be strong, with most investment in peak capacity being gas fired. Increases in the share of gas, however, are expected to be modest because gas resources are located mainly in the north west of the economy, whereas the major demand centres are in the east. Gas prices are also likely to be prohibitive for base load power generation plants (Akmal et al. 2004).

There have, however, been policy initiatives at the state level to encourage the development of gas fired power generation capacity. The Queensland Government, for example, has mandated that a minimum of 13 per cent of electricity will be generated from gas by 2005. The New South Wales Government's 2003 Greenhouse Gas Abatement Scheme places a cap on the quantity of carbon dioxide that a distributor can emit in retailing electricity. This will also be a driver for increases in thermal efficiency as the cap is gradually reduced over the period to 2012 (Akmal et al. 2004; New South Wales Government 2004). These initiatives may, in part, address the challenge of increasing the share of efficient gas fired power generation to meet peak power demand. Although some demand is currently met by efficient gas fired power generation plant such as NGCC, much depends on coal fired and simple cycle gas fired power generation. A nationally coordinated end use efficiency program has also been implemented to address demand side management objectives (ESAA 2004).

The Australian Government has developed a broad range of measures aimed at improving energy efficiency and reducing greenhouse gas emissions (AGO 2004b). The Mandatory Renewable Energy Target (MRET) was set by the Australian Government in 2000 and places a legal liability on wholesale purchasers of electricity (retail electricity companies) to purchase an additional 9500 GWh of renewable energy annually by 2010. The MRET scheme seeks to increase electricity generation capacity from biomass (mainly bagasse, woodwaste and bagasse/woodwaste cogeneration) and wind, although the shares are likely to remain small.

Australia is also working toward world's best practice efficiency in fossil fuel power generation. Mandated electricity generation efficiency standards, requiring movement to world's best practice for existing and new power generation plant Australiawide, have also been introduced in an effort to reduce greenhouse gas emissions (AGO 2000b). To this end, Australia has made further developments in advanced coal technologies, particularly PFBC and IGCC. Immediate research priorities include the construction of a black coal (and perhaps also a brown coal) IGCC demonstration power generation plant with the potential to further test carbon capture and storage technologies and an investigation of the potential for oxyfuel combustion sometime thereafter (Coal21 2004).

People's Republic of China

Economic growth in China has expanded at an average annual rate of almost 10 per cent for more than twenty years, with significant implications for the energy sector. Energy supply has been one of the highest priorities for national investment over recent decades, particularly the expansion of electricity generation capacity (Levine and Sinton 2004). China's energy sector is expected to continue to grow rapidly over the coming decades driven, in part, by increased domestic demand and partly by expanded trade as a result of its accession to the World Trade Organisation. China is the world's second largest producer of electricity and accounts for the second largest share of electricity generation capacity (APEC 2003).

Since 2002, there have been widespread power shortages in China, resulting in power rationing, brownouts or blackouts. The inability to meet demand for electricity was, among other factors, the result of shortages in capacity and was exacerbated by insufficient transmission capacity. In response to the power shortages, there has been an increase in power generation plant and transmission construction, as well as recognition by government of the role of increasing energy efficiency and demand side management in reducing demand. However, significant future investment in power generation and transmission infrastructure is needed in the next two to three decades to meet demand projections. It is estimated, for example, that investment requirements in China's power generation and transmission sectors to 2020 total more than US$1000 billion, almost half of all investment required in the APEC region. China is expected to account for around 15 per cent of all additions to electricity generating capacity in the APEC region over the period to 2020 (APERC 2003; IEA 2004b). The commissioning of new capacity at this scale provides significant opportunities to improve the operational performance of the power generation sector in China.

China's energy use, and coal use in particular, has had significant environmental consequences, with only a third of cities meeting international air quality standards. Coal fired electricity generation is a significant contributor to these problems in some areas.

Beginning in the 1990s, Chinese authorities encouraged fuel switching from coal to cleaner fuels, the use of non fossil fuel energy sources including hydropower and nuclear, and introduced both production and demand side energy efficiency initiatives in the power sector. A number of smaller, less efficient thermal power generation plants, most of which were not fitted with modern pollution control devices, have been shut down in recent years. This trend, combined with the development of emission control technology and the strengthening of environmental protection management in the power industry, has resulted in some progress toward pollution mitigation in China.

Current status of technology

China's electricity generation was 1640 TWh in 2002 and total generating capacity was around 353 gigawatts (table 4) (IEA 2004a). Fossil fuel fired power generation accounted for more than 80 per cent of total power generation in 2002, with the remainder coming mainly from hydropower and some nuclear power generation (APEC 2003).

4 Electricity generation in China, 2002

Fuel	**Output** [a]	**Average thermal efficiency** [b]	**Key technologies**
	TWh	%	
Coal	1 271	30	PC – subcritical
Oil	49	25	Simple cycle
Gas	4.7	33	Simple cycle
Nuclear	25		
Hydro	288		
Other renewables	0		
Total output	1 638		
Total capacity (GW)	353		

a Sourced from IEA Energy Balance (2004a). **b** Average thermal efficiencies are in LHV terms and derived from IEA (2002a) data presented in *World Energy Outlook 2002.*

Supported by China's abundant coal reserves, more than 95 per cent of thermal capacity is coal fired and less than 5 per cent is oil or gas fired. Of the coal fired capacity, almost all is subcritical pulverised coal, with a small share (less than 5 per cent) of supercritical in 2000 (table 2). Fluidised bed technology accounted for less than 1 per cent of coal fired power generation capacity in 2000. Supported by the National Development and Reform Commission, a 300 megawatt FBC unit is under construction at the Baima power generation plant in Sichuan Province. A further development will be the demonstration of a 600 megawatt FBC boiler with supercritical steam performance.

Almost half of China's oil fired capacity is simple cycle, while around 20 per cent is combined cycle or combined heat and power. Combined cycle and combined heat and power accounted for more than 40 per cent of gas fired capacity in 2000, although this is a relatively small proportion of overall generating capacity. Simple cycle gas accounted for much of the remainder of gas fired capacity (APEC 2001).

China has introduced combined heat and power (CHP) stations for urban heating using waste heat from thermal power stations. However, the majority of these cogeneration plants have low overall efficiency and high thermal losses in distribution. Chinese central heating systems are generally not designed so that individual users can determine room temperature in the cold season and heat is not paid for by users on the basis of actual consumption. Northern China has a climate that is suitable for CHP, but the present cogeneration plants operate only when there is demand for heat (typically seven to eight months a year) and remain idle for the rest of the time as the efficiency of the cogeneration plants is too low when producing electricity only (Martinot 2001).

Regulations on emissions of particulates and sulfur dioxide were first introduced in 1991. In medium and large scale coal fired power generation plants, China has made progress in limiting particulate emissions using electrostatic precipitators and sulfur dioxide emissions through flue gas desulfurisation equipment in areas with especially low air quality. In general, however, the effectiveness of this equipment is relatively low (World Bank 2001).

Emission control technologies are expected to become more widespread as the economy moves toward stricter environmental protection regulations.

Current policy is that FGD units will be required at all newly built coal fired power generation plants. This, together with declining capital costs, is expected to be the driver behind an increase in the use of environmental technologies (Nautilus Institute 1999; Japan Corporate News 2004).

There have been efforts in China over recent years to improve the thermal efficiency of power generation plants. Many outdated, small and inefficient power generation plants have been decommissioned and replaced with large scale plants. Currently, 50 per cent of installed thermal generating capacity consists of plants with a capacity of 200 megawatts or more. Despite these efforts, the average efficiency of thermal power generation remains below that of OECD economies. The thermal efficiency of coal fired power plants in China ranges from 27 to 30 per cent, compared with around 35 per cent in OECD economies (IEA 2002a; Lam and Shiu 2004). The comparatively low energy efficiency of power generation in China is partly a result of the use of low quality coal, coupled with insufficient power generation plant maintenance. In general, power generation plants with access to higher quality coal and independent power producers achieve greater levels of thermal efficiency than those run by the State Power Corporation (Lam and Shiu 2004).

There has also been increasing emphasis on the modernisation of existing power generation plants, with the main objective being to increase the combustion efficiency of domestically manufactured boilers and to optimise steam turbine efficiency. A number of Chinese boiler manufacturers are now producing 600 megawatt models with almost comparable performance and quality to models produced internationally. These developments have been facilitated by technology transfers from foreign manufacturers and active promotion by government (Nautilus Institute 1999; Martinot 2001).

Future directions for electricity generation

The Tenth Five Year Plan (2001–05) calls for a reduction in dependence on coal by developing oil and gas infrastructure, the use of renewable energy sources and by promoting energy efficiency. In line with this plan, the State Power Corporation, which owns half of China's electricity generating capacity, has placed priority on the development of cleaner coal fired capacity, hydroelectric and natural gas fueled capacity, and is also promoting the use of renewable energy sources such as wind and solar, particularly in remote areas (SPC 2004). Over a longer horizon, development of the national clean coal development program to further encourage the application of clean coal technologies, including more FBC and PFBC power generation plants, IGCC and supercritical PC fired plant is also planned (APERC 2003).

In 2002, China's government approved thirty major new electric power projects, with a total of around 22 gigawatts of capacity (IEA 2002a). While there are hydropower and nuclear plants proposed or under construction, China's dependence on coal for power generation is not likely to change significantly in the next three decades and more than 90 per cent of government approvals in 2003 were for coal fired capacity. This is because China has abundant coal reserves and coal fired electricity generation costs are relatively low. However, there is an emphasis on building large (above 300 megawatts) power plants that use more efficient technologies (Lam and Shiu 2004).

The Tenth Five Year Plan also aims to enhance environmental protection standards. Stricter emission regulations, larger shares of cleaner coal and gas fired electricity generation technologies and improvements in energy efficiency have been highlighted as means to achieve this goal. These policies will have an impact on future technology choices in China, particularly if emission standards are strictly enforced. Historically, PC plant without FGD has been the dominant technology because it is the least expensive option to meet growing demand for electricity. However, PC plant with FGD is likely to dominate the electricity generation mix in coming years as new plants are required to have sulfur dioxide emission control technologies fitted, even in inland areas that were previously exempt.

The Chinese Government has plans to build the first pilot IGCC plant in a developing economy. The proposed plant will have 400–500 megawatts of capacity and will demonstrate the technology's ability to reduce sulfur dioxide, nitrogen oxide and carbon dioxide emissions as well as its operational performance at a commercial scale. If the new technology is successfully demonstrated, three to five more IGCC power generation plants with 1200–2000 megawatts of total capacity are planned for construction during the Twelfth Five Year Plan period 2011–15. Beyond that, the Chinese Government has ambitious plans for IGCC technology, with projected installation of 30 gigawatts of IGCC capacity by 2030 (Power in Asia 2004).

As gas is generally not cost competitive with coal for base load power, NGCC power generation plant is not likely to be widespread in China. However, there is expected to be strong growth in gas fired power generation in coastal areas where economic growth is high and imports of liquefied natural gas are likely to be available. To date, all proposed LNG terminals in China are closely associated with plans to expand gas fired power generation capacity. As with IGCC, much of the research and development of the NGCC technology occurs internationally and it is possible that the capital cost of NGCC power generation plant could decline if production of the technology was undertaken in China.

In recent years, China has imported power generation plant, as well as environmental technologies, from Japan, the United States and other economies, often under joint venture agreements (see, for example, Japan Corporate News 2004). Further liberalisation of trade and investment regimes will open up opportunities for China to import more advanced power generation and environmental technologies.

Korea

Energy consumption in Korea increased at an average annual rate of 7.5 per cent between 1990 and 2000, exceeding the economic growth rate of 6.2 per cent over the same period. Korea is highly dependent on imported energy, with imports meeting more than 97 per cent of the economy's energy requirements in 2002, excluding nuclear (Ball et al. 2003). This reflects the fact that Korea has very limited indigenous energy resources.

In light of Korea's heavy dependence on energy imports, the government has developed policy responses in the electricity sector that include demand side management and the promotion of a diversity of fuel sources for electricity generation, including nuclear energy and renewables. Key energy policies have been driven by the need to support high levels of economic growth, despite limited indigenous energy resources (MOCIE 2004a).

The Korean Government has been heavily involved in the energy sector, including through the management of companies such as the Korea Electric Power Company (KEPCO) and this has enabled regulation of energy prices. Korea has been progressing toward a more market oriented energy sector and a program for unbundling and privatising KEPCO has been developed. The proposal splits the power generation arm of KEPCO into six companies that are intended to be privatised in stages. Forty-two thermal power generation plants were divided among five electricity generation entities of similar capacity, while nuclear power generation plants were grouped into one entity. The objectives of the restructuring include promoting efficient and stable electricity supply and expanding electricity demand choices for consumers (APEC 2003; MOCIE 2004a).

Current status of technology

Electricity is expected to continue to be Korea's fastest growing final energy source. Electricity generation was just over 3200 TWh in 2002 (table 5) and installed capacity was almost 54 gigawatts in the same year. This had increased to around 56 gigawatts in 2003, a twofold increase over the previous decade (APEC 2001; MOCIE 2004b).

In order to reduce dependency on imported oil, construction of oil fired power generation plants has been strictly controlled and development of non oil power sources such as coal, gas and nuclear has been promoted. The share of oil fired power generation capacity has decreased since the late 1990s and currently represents around 10 per cent of total capacity. Coal fired power generation plants currently account for around 25 per cent of installed capacity. Gas fired power generation plants were introduced into Korea in 1986 and the share of gas fired capacity has increased steadily over the past ten years to account for around 25 per cent of installed capacity. Nuclear power generation plants have been generating electricity in Korea

5 Electricity generation in Korea, 2002

Fuel	Output[a]	Average thermal efficiency[b]	Key technologies
	TWh	%	
Coal	131	42	PC – supercritical
Oil	31	36	Simple cycle – subcritical
Gas	42	45	Combined cycle / combined heat and power
Nuclear	119		
Hydro	3		
Other renewables	<1		
Total output	326		
Total capacity (GW)	54		

a Sourced from IEA Energy Balance (2004a). **b** Average thermal efficiencies are in LHV terms and are derived from IEA (2002a) data presented in *World Energy Outlook 2002.*

since the 1970s and the installed capacity of domestic nuclear power generation is 15 gigawatts with seventeen units in operation. Nuclear power accounted for 36 per cent of total power generation in 2001. There is a small amount of hydropower generation in Korea (APEC 2001; MOCIE 2004b).

There has been a focus on environmental protection in Korea in recent years and emission standards, charges and restrictions have been implemented for sulfur dioxide and nitrogen oxide emissions from thermal power generation plants. KEPCO has promoted the development of state of the art coal fired power generation plants in response to these environmental standards and energy efficiency initiatives implemented by government.

To improve thermal efficiency, KEPCO has placed emphasis on building large scale (over 500 megawatts) power generation plants with supercritical and, more recently, ultra supercritical boilers, as well as expanding the overall capacity of gas fired combined cycle units. Consequently, almost 60 per cent of coal fired capacity in Korea is supercritical pulverised coal (table 2). Much of the remainder is subcritical pulverised coal and less than 5 per cent is FBC. Because of the large share of large scale supercritical coal fired power generation plants, the average thermal efficiency of coal fired power generation in Korea is high by world standards.

Korea has also adopted efficient gas fired technology with around 60 per cent combined cycle or combined heat and power. Almost 35 per cent of gas fired capacity is subcritical steam turbine and the remainder is simple cycle gas (APEC 2001).

Power generation from coal fired power generation plants in Korea has led to high levels of sulfur dioxide, nitrogen oxide and carbon dioxide emissions. Current emission standards for sulfur dioxide and nitrogen oxides mean that FGD or low nitrogen oxide burners are required for most coal fired power generation plants in Korea. Power generation plants that do not have FGD fitted are restricted to using low sulfur (less than 1 per cent) coal. Two power generation plants that were recently commissioned have flue gas treatment systems for nitrogen oxides and Korea plans to extend the use of flue gas systems such as selective catalytic converters (SCR) to existing power generation plants as well as those being constructed. Korea has also formulated a comprehensive plan to reduce its carbon dioxide emissions through further improvements in thermal efficiency, and the promotion of gas fired, nuclear and renewable energy (MOCIE 2004d).

Future directions for electricity generation

Demand for electricity is expected to increase substantially over coming decades in Korea. The electricity plan 2002–15 projects that power generation capacity will need to increase from around 54 gigawatts in 2001 to around 77 GW in 2015 (MOCIE 2004a). However, fuel shares in the electricity generation sector are not expected to change substantially. Coal fired power generation is expected to remain a large share of capacity (around 30 per cent to 2015) and KEPCO has plans to construct two highly efficient advanced coal fired power generation plants, either IGCC or PFBC, in 2005 and 2012. The operational and economic success of these power generation plants will be a key determinant of the future adoption of these technologies (MOCIE 2004a).

Gas fired power generation plants are expected to retain a 25–30 per cent share of installed capacity to 2015. Gas fired power generation plants are planned as peaking capacity and, as such, will contribute 10–15 per cent of electricity generation to 2015. New gas fired power generation plants are expected to use combined cycle technology.

It is expected that nuclear power generation plant construction will continue to be promoted in Korea for the supply of electricity, with government plans to increase the share of nuclear capacity to around 35 per cent by 2015. However, there is strong public opposition to nuclear power in Korea (MOCIE 2004c). Consequently, it will become increasingly difficult to secure sites, and construct and operate new nuclear power generation plants in the future despite government efforts to promote nuclear as a clean and stable energy source.

The Korean Government also plans to increase the share of new and renewable energy from 2.1 per cent in 2003 to 5 per cent of total primary energy consumption by 2011. To date, there has been little investment in the development of new and renewable energy technologies (MOCIE 2004a). The government has set targets for renewables with a focus on the development of biomass, photovoltaics and hydrogen fuel cells. Plans are also under way to develop wind and tidal power generation plants by 2011. Korea is a strong supporter of international cooperation to facilitate technology transfer and has a number of multilateral and bilateral agreements to promote information exchange and dissemination, joint research and the establishment of long term strategies to resolve energy issues, particularly within the north east Asia region (MOCIE 2004a,b).

Mexico

In the past twenty years, there have been contrasting cycles of economic activity in Mexico, with periods of growth interrupted by recession. Growth in electricity generation has increased over the past decade at an average annual rate of 5.2 per cent. Historically, there has been considerable government intervention in Mexico's energy sector that has restricted the participation of private investors. The Federal Electricity Commission (CFE) is the dominant electricity generator in Mexico and has a monopoly on electricity transmission and distribution.

Since the 1990s, the government has undertaken reforms to promote the liberalisation of energy markets to augment both private and foreign investment, foster competition and to enhance energy quality and supply. To date, there has been limited private involvement in power generation, with independent power producers currently accounting for only a small proportion of electricity generation capacity. Proposed reforms will allow private generators to compete with government owned utilities in wholesale markets. This should provide further incentives to invest in power generating capacity and energy efficient technologies (APEC 2003).

Current status of technology

Total electricity generation in 2002 was more than 215 TWh (table 6). Electricity generation capacity was more than 42 gigawatts in 2001, 87 per cent of which was owned by the two state owned electricity monopolies, CFE and the smaller Luz y Fuerza Centro. Electricity generation is expected to increase by an average of 3.5 per cent a year over the period to 2030, in line with reforms proposed to promote economic growth (IEA 2002a; APEC 2003). Mexico is a small net importer of electricity from the United States to supply markets in the north where capacity is inadequate to meet demand. At present, power trade between Mexico and the United States is severely restricted by limited power transmission capacity.

Mexico is well endowed with oil and gas resources. Oil is the dominant fuel for electricity generation in Mexico, accounting for almost 50 per cent of capacity in 2001. However, many of the oil fired power generation plants have been, or are planned to be, converted to natural gas. The remainder of capacity in 2001 was made up of natural gas and coal (APEC 2001; EIA 2002). Hydropower, geothermal, nuclear and wind power accounted for small shares of generating capacity in 2001.

Oil fired power generation capacity in Mexico is predominantly subcritical steam turbine (around 38 per cent of total capacity) (table 2). Mexico has almost 2300 megawatts of gas fired combined cycle power generation plant, which accounts for around half of all gas fired capacity. Several new natural gas fired combined cycle power generation plants are currently planned, under construction or have been completed since 2001. The existing units are typically dual fueled with natural gas and distillate.

The most efficient natural gas fired combined cycle power generation plant, Samalayuca II, operates at a thermal efficiency of more than 47 per cent. More typically, NGCC power generation plants in Mexico reach efficiencies of 35–42 per cent. The remaining gas fired power generation capacity consists of steam turbines or simple cycle gas that operate at efficiencies of 20–35 per cent. All coal fired capacity is subcritical PC technology (APEC 2001; IEA 2002a).

Coal fired power generation plants in Mexico are generally fueled with relatively low sulfur content coal and of the two coal fired power stations installed in 1999, one was equipped with nitrogen oxide control technologies. The more recent gas fired capacity, such as Samalayuca II, is equipped with burners designed to reduce nitrogen oxide emissions and with selective

6 Electricity generation in Mexico, 2002

Fuel	**Output** [a]	**Average thermal efficiency** [b]	**Key technologies**
	TWh	%	
Coal	26	33	PC – subcritical
Oil	79	36	Steam turbine – subcritical
Gas	69	38	Combined cycle / combined heat and power
Nuclear	10		
Hydro	25		
Other renewables	6		
Total output	215		
Total capacity (GW)	42		

a Sourced from IEA Energy Balance (2004a). **b** Average thermal efficiencies are in LHV terms and are derived from IEA (2002a) data presented in *World Energy Outlook 2002.*

catalytic converters. As some of the new and proposed capacity additions are near the Californian border, Mexico is under increasing pressure to meet Californian environmental standards (Miller, Patterson and Vaughan 2001; PBS 2003).

Future directions for electricity generation

Gas and renewable energy offer the opportunity for Mexico to reduce its dependence on oil for electricity generation. Projections indicate that an additional 26 gigawatts of capacity is needed to meet Mexico's electricity demand growth between 2003 and 2012, of which more than half is already under construction. Three quarters of the capacity currently under construction is NGCC, with two gas fired power generation plants exceeding 1000 megawatts of capacity. The remaining capacity that is currently under construction consists of approximately 1600 megawatts of hydropower, 700 megawatts of coal fired power generation plant and small additions of geothermal, diesel combustion and single cycle gas turbines (Secretary of Energy 2003).

There is approximately 13 gigawatts of planned capacity additions that have not yet begun construction. Of those currently committed, around 1000 megawatts is NGCC and 900 megawatts is hydropower. A 100 megawatt wind farm in southern Mexico is also planned for completion in 2005. Planned additions to capacity, less retirements, indicate that total installed power generation capacity should reach around 63 gigawatts by 2012 (Secretary of Energy 2003).

For the electricity generation mix beyond 2012, the Mexican Government plans to have up to 75 per cent of its additional power generation capacity using combined cycle natural gas technology. Oil fired capacity is expected to increase slightly, but its share is expected to fall as gas becomes the dominant fuel. Coal will probably account for a small share (less than 10 per cent) of additional capacity. Imports of coal from the United States, Canada and Colombia are expected to rise to meet additional demand from both the electricity and steel production sectors.

The Mexican Government also has a policy to promote the further development of other renewable energy sources beside wind and hydropower. Solar power and biomass are being promoted in isolated rural communities where connection to the national grid is costly (EIA 2002; APEC 2003).

Thailand

Energy consumption has grown strongly in Thailand over the past two decades, although it was disrupted during the Asian financial downturn in 1997-98. Since the downturn, electricity consumption has grown rapidly as a result of increased growth in all economic sectors. The Electricity Generating Authority of Thailand (EGAT) released the Thailand Power Development Plan in August 2004 that outlines the expected expansion in the power sector over the period 2004–15. The plan incorporates the government's policies on peak demand shaving to reduce investment in peak load power generation plant installation, and its collaborative energy strategy with neighboring economies (EGAT 2004).

Over the past decade, the energy sector in Thailand has been progressively deregulated, with the objective of increasing competition and economic efficiency, particularly in the electricity market. In 1995, the independent power producer (IPP) program was launched in an effort to partly privatise the state controlled power utilities. In 2000 some power generation plants were split off from the government owned utility and sold to the private sector in order to increase competition in electricity generation. While the share of privately owned capacity has increased more than threefold since the mid 1990s, almost two thirds of installed capacity in Thailand is currently government or state owned. Private investment in power generation capacity has, however, relieved some of the burden on EGAT to meet increasing electricity demand.

Current energy policies focus on the conservation of energy and meeting more stringent environmental standards. Policy measures include substituting natural gas for coal and fuel oil in electricity generation, promoting clean coal technologies and implementing more stringent sulfur dioxide and carbon dioxide emissions standards for power generation plants. The Thai Government is actively promoting the development of renewable energy sources including hydropower and solar power through research and development funding and subsidies (EPPO 2000, 2002; APEC 2003).

Current status of technology

Total electricity generation in Thailand was more than 107 TWh in 2002, almost all of which was generated domestically using fossil fuel sources (table 7). Thailand had around 25.7 gigawatts of power generation capacity in March 2004, of which around 150 gigawatts is owned by EGAT (EGAT

2004). Natural gas is the most important fuel source and gas fired power generation plants accounted for more than half of Thailand's installed generating capacity in 2001. Coal fired power generation plants accounted for a further 15 per cent of installed capacity and have held a fairly constant share since 1991. Less than 5 per cent of installed capacity is oil fired. Thailand's remaining power capacity is provided by various hydroelectric, geothermal, solar and wind turbine power generation plants.

To supplement domestic production and manage peak loads, Thailand imports a small quantity of electricity from the Lao People's Democratic Republic (APEC 2001, 2003; DEDE 2002).

In response to concerns about high oil import dependency, a program for the conversion of almost all oil fired electric power generation plants to natural gas was completed in 2001. The share of combined cycle gas technology more than trebled in capacity between 1991 and 1992 and has continued to increase steadily since then (DEDE 2002). Increases in the following decade have resulted in gas fired combined cycle power generation plants becoming the dominant technology in Thailand, accounting for almost 60 per cent of gas fired capacity in 2001 (table 2). Subcritical gas fired steam turbines accounted for almost a third of gas fired capacity in the same year

7 Electricity generation in Thailand, 2002

Fuel	**Output** a	**Average thermal efficiency** b	**Key technologies**
	TWh	%	
Coal	18	34	PC – subcritical
Oil	3	37	Simple cycle – subcritical
Gas	79	44	Combined cycle / combined heat and power
Nuclear	0		
Hydro	7		
Other renewables	<1		
Total output	107		
Total capacity (GW)	25.7		

a Sourced from IEA Energy Balance (2004a). **b** Average thermal efficiencies are in LHV terms and are derived from IEA (2002a) data presented in *World Energy Outlook 2002.*

and much of the remainder was simple cycle gas. The share of both of these technologies decreased between 1991 and 2001 as the share of combined cycle power generation plants increased.

The share of gas fired combined heat and power generation capacity has also increased in the past decade, but from a very low base. Of coal fired capacity, more than 80 per cent was subcritical pulverised coal, with the remaining 20 per cent being FBC. All coal fired power generation plants have been fitted with FGD. In power generation plants using lignite as the fuel stock, the lignite is blended with higher quality coal in order to meet environmental standards (APEC 2001; DEDE 2002; EPPO 2004a).

The thermal efficiency of power generation plants in Thailand is generally high, with new combined cycle gas fired power generation plant approaching world's best practice. While many older coal fired power generation plants have thermal efficiencies of between 30 and 35 per cent, efficiencies derived from IEA data suggest that the average thermal efficiency of coal fired power generation plant is around 34 per cent (table 7).

Future directions for electricity generation

EGAT forecasts an increase in average annual demand for electricity of 6–7 per cent over the period to 2015. Increases in demand to 2010 will be met through the commissioning of around 9000 megawatts of capacity. Some of this capacity will be commissioned in neighboring economies, such as the Nam Theun II hydroelectric project in Lao People's Democratic Republic.

The Thai Government is promoting indigenous natural gas as the economy's major source of energy and the majority of capacity additions are expected to be combined cycle gas. The remaining additions to generating capacity are likely to be pulverised coal and hydro, as well as other renewable energy sources after 2008. An additional 13 000 megawatts of capacity is planned for commission between 2010 and 2015, taking total installed capacity to more than 47 000 megawatts in 2015 (EPPO 2001; APEC 2003; EGAT 2004).

Increases in coal fired capacity are planned, partly in response to energy security concerns. However, opposition from environmentalists and local communities has forced the Thai Government to postpone two new coal fired power projects in southern Thailand and it is now considering finding new locations or switching to natural gas as a fuel (IEA 2002a).

The government has set a national goal to increase the share of renewable energy in the total energy mix (also including the transport sector) to 8 per cent by the year 2011. To support this goal, the PDP has established the Renewable Portfolio Standard, which requires 5 per cent of power generation capacity additions to be from renewable energy sources. State funded photovoltaic power systems have been used in Thailand for more than 25 years to provide offgrid electricity to rural areas.

Further research is being undertaken to develop wind, solar, biomass and hybrid power generation potential. Small and mini/micro hydropower generation plants (less than 20 megawatts) are also planned to boost rural electrification. These power generation plants use existing irrigation weirs to produce electricity and, if fully utilised, could represent up to 350 megawatts of installed capacity. Twenty Small Power Producer projects have been approved for subsidy totalling 38 megawatts using water resources from three irrigation dams (EPPO 2004b).

United States

The United States is the largest producer, consumer and exporter of energy in the world. It is resource rich with significant reserves of oil, natural gas and coal. Energy policy in the United States is focused on, among other things, improving energy security by boosting indigenous energy supplies, especially oil and gas, and curbing emissions of greenhouse gases. The Department of Energy (DOE) is responsible for implementing policies and programs that monitor the state of energy markets, maintain energy security and support research and development of new energy technologies, including clean coal technologies. The United States has achieved a high level of competition in its electric power markets, including the power generation sector.

Government and industry support for new energy efficient technologies has resulted in several pilot projects to improve thermal efficiencies and power generation plant reliability, and to reduce capital and operating costs of advanced technologies. Since the United States obtains more than half of its electricity from coal fired power generation plants, emphasis has been placed on limiting greenhouse gas emissions. Reductions in carbon dioxide, sulfur dioxide and nitrogen oxide emissions have been achieved through a combination of power generation plant specific air quality limits and a system of emissions trading (USDOE 2004a).

Current status of technology

In 2002 the United States generated around 3900 TWh of electricity, including around 100 TWh from combined heat and power (CHP) plant in the commercial and industrial sectors (table 8). In the electricity generation sector, coal fired power generation plants accounted for 53 per cent of electricity generation, nuclear 21 per cent, natural gas 15 per cent and hydroelectricity 7 per cent (EIA 2002).

Electricity generation capacity was 813 gigawatts in 2001. Thermal power sources account for around three quarters of power generation capacity, around 40 per cent of which is coal fired. Investment in coal fired power generation generally has been less attractive than natural gas in recent years as a result of relatively high capital costs and longer construction periods (EIA 2002).

Around two thirds of coal fired technology is subcritical PC with 25 per cent of the remainder being supercritical PC (table 2). The Clean Air Act Amendments of 1990 favored the use of coal with low sulfur content and many generators have switched from higher sulfur coal to low sulfur coal, incurring relatively modest capital investments. Subcritical steam turbines are the predominant gas fired technology and combined cycle and simple

8 Electricity generation in the United States, 2002

Fuel	Output[a]	Average thermal efficiency[b]	Key technologies
	TWh	%	
Coal	2 047	33	PC – subcritical
Oil	99	35	Steam turbine – subcritical
Gas	712	35	Steam turbine – subcritical
Nuclear	805		
Hydro	234		
Other renewables	26		
Total output	3 922		
Total capacity (GW)	813		

a Sourced from IEA Energy Balance (2004a). **b** Average thermal efficiencies are in LHV terms and are derived from IEA (2002a) data presented in *World Energy Outlook 2002.*

cycle gas turbines each account for around 25 per cent of gas fired capacity. While many older oil and natural gas fired steam power generation plants in the United States have efficiencies of less than 30 per cent, combined cycle power generation plants have efficiencies of around 43 per cent (AGO 2000b).

The United States has placed less emphasis on improving the efficiency of coal fired power generation plants and, instead, shifted more to natural gas for new power generation. Most of the recent additions to capacity have been gas fired — of the 187 gigawatts of capacity added in 2002 and 2003, 110 gigawatts was NGCC. There is also a small, but increasing share of supercritical steam turbine power generation plants that are coal fired in the United States.

The United States has been at the forefront of IGCC technology with 250 megawatts demonstration power generation plants installed and operating in the states of Florida and Indiana. At the Indiana site, a vintage coal fired power generation plant was retrofitted with advanced technologies that more than doubled capacity, and improved the thermal performance of the power generation plant from 32 per cent to about 38 per cent (AGO 2000b; APEC 2001; IEA 2004b).

Future directions for electricity generation

The United States will need to install new capacity as demand grows and older, inefficient power generation plants are retired. Some power generation plants that do not meet current emission standards will either be retired or refurbished. Large scale retirement of 62 gigawatts of fossil fuel fired baseload power generation plants is planned. It is likely that these power generation plants will be replaced with clean coal technology or natural gas in order to meet the requirements of the Clean Air Act Amendments of 1990 (EIA 2004).

While gas is expected to make up the largest share of the fuel mix for new capacity, issues such as gas pipeline bottlenecks and fluctuating prices mean that coal will remain an important source of fuel for power generation. Two coal fired power generation plants with a capacity of 1000 megawatts are to be completed in 2006, and further increases in coal fired capacity are expected to be brought on line before 2030. Most of the increase in coal fired capacity is expected to be either supercritical or ultra supercritical pulverised coal. It is expected that the majority of additional gas fired capacity that will be installed before 2030 will be NGCC. There are also plans to retrofit emission control equipment in order to comply with state and federal air quality initiatives for sulfur dioxide and nitrogen oxides. The technologies are likely to be FGD and SCR (EIA 2004).

Since 2002 there have been a number of initiatives developed by the federal government to reduce the greenhouse gas intensity of electricity generation, including tax incentives for renewables and cogeneration and measures to enhance the capture and storage of carbon, including geosequestration. While some of these initiatives are likely to provide an incentive to move away from fossil fuel energy sources, electricity generation from renewable energy is expected to remain a small share of the generation mix.

Potential for technological advancement in the electricity sector

In the electricity generation sector, there is considerable variation in the choice of technologies and thermal efficiencies across the six focus economies. Generally, economies with limited indigenous resources have adopted thermally efficient coal or gas fired power generation technologies in conjunction with a combination of non fossil fired power generation technologies, including nuclear power and hydropower. All of the focus economies have plans to promote the further development of electricity generation from renewable energy sources, although this is not expected to become a major share of the fuel mix over coming decades.

Across APEC coal is the dominant fuel for power generation, accounting for 46 per cent of total electricity output in 2002. While coal has economic advantages over gas in economies with abundant reserves and is likely to remain the dominant fuel source in the power generation sector, it carries an environmental burden. Coal is the most carbon intensive fuel in terms of carbon dioxide emissions per energy unit and the dominant technology choice — subcritical pulverised coal — is now regarded as relatively inefficient compared with newer, more advanced coal fired technologies such as supercritical and ultra supercritical pulverised coal.

The relatively low thermal efficiency of coal fired power generation plant in the APEC region has significant implications for carbon dioxide and other greenhouse gas emissions. The average thermal efficiency of coal fired power generation plant in APEC has been estimated to be between 27 and

38 per cent (APEC 2001). In comparison, the average efficiency of coal fired power generation in OECD economies is around 36 per cent. This means that one unit of electricity produced in a coal fired power generation plant operating at a thermal efficiency of 30 per cent, for example, emits 20 per cent more carbon dioxide than a unit of electricity produced in an OECD coal power generation plant. This highlights the environmental benefits of adopting more thermally efficient technologies that can minimise the environmental impacts of coal fired generation.

Natural gas fired power generation has environmental advantages over coal fired power generation in that it produces less carbon dioxide emissions per unit of output and there are no sulfur dioxide emissions. While natural gas is less carbon intensive than coal, significant reductions in emissions of carbon dioxide can be achieved with improvements in thermal efficiency or by adopting more thermally efficient gas fired power generation technologies. The pattern of adoption of gas fired power generation technologies is similar to coal in that the most common gas fired power generation technology across the APEC region is the subcritical steam turbine which, again, is regarded as relatively inefficient when compared with more advanced technologies such as NGCC.

In contrast, the most thermally efficient gas fired power generation technology, NGCC, accounted for around a quarter of gas fired installed capacity in the APEC region in 2001. The broader adoption of this technology has been limited in the past in some economies by high and fluctuating natural gas prices, which make NGCC less cost competitive with coal fired power generation technology for base load capacity. In several of the focus economies, however, proportionately large increases in NGCC are planned for future additions to power generating capacity.

A key finding in this chapter is that the relatively low average thermal efficiencies of fossil fuel fired electricity generation plant in the APEC region have important implications for fuel consumption and for emissions of greenhouse gases and other pollutants. Given the scale of power generation across the APEC region and the magnitude of required capacity additions in many economies, there is significant opportunity to improve average efficiency and reduce growth in energy consumption and greenhouse gas emissions by adopting more advanced technologies whether refurbishing existing capacity or building new capacity.

While the gap in thermal efficiencies between less technologically advanced economies and those with more advanced power generation technologies is expected to narrow between now and 2030, it is not expected to close. The rate at which more advanced power generation technologies are developed and adopted is an important determinant of the extent to which the thermal efficiency gap can be closed. The role of research and development and technology transfer in accelerating the rate of technology adoption as a means of reducing this efficiency gap between economies is explored in chapter 5.

4

technology characteristics of the iron and steel sector in APEC

- Economies in the APEC region employ a wide range of technologies in the iron and steel sector. These technology choices are influenced by a number of economy specific characteristics, including natural resource endowments, energy prices, the ability to raise investment capital and the availability of scrap supplies.

- Integrated steel production routes accounted for more than 60 per cent of steel produced in APEC in 2002. This is despite an increase in the share of electric arc furnace based production across most member economies, except China, over the past decade. The blast furnace – basic oxygen furnace route produced the vast majority of integrated steel output.

- In general, scrap based electric arc furnaces are less energy intensive than blast furnace based integrated steel mills. Steel making technologies are typically more energy efficient in economies such as Japan and Korea where high energy costs and stringent environmental standards have fostered the adoption of energy saving technologies.

- A range of new technologies, particularly related to casting and iron making, are under development that could affect energy consumption in the industry significantly. The net effect of these technologies on energy consumption will depend on which of these technologies are commercialised.

- In this context, technology transfer to economies with less energy efficient steel industries and structural changes that increase the share of steel produced in electric arc furnaces in the most energy efficient economies provide the most potential for energy efficiency gains in the iron and steel industry.

As discussed in chapter 2, the industry sector as a whole is a major source of energy consumption in APEC, accounting for around a third of final energy consumption and more than 40 per cent of all electricity consumption in the region in 2002 (IEA 2004a). Despite the large number of industries operating throughout APEC, more than half of this energy was consumed in a few industries. These include petroleum refining and the production of chemicals, steel and other nonferrous metals. Because of the substantial energy consumption in these industries, the growth of energy consumption in APEC over the coming years will be significantly influenced by changes in output and energy efficiency in these sectors (Kroeze et al. 2004; Worrell and Price 2001). These changes in output and efficiency could be influenced by a number of factors, including the pattern of economic growth and the types of technologies introduced throughout the region.

In order to better understand how output and energy efficiency in energy consuming industries could evolve over the period to 2030, this study includes a detailed analysis of current and projected energy consumption in the steel industry. The steel industry is chosen for analysis because of its high energy intensity and because it is present, to varying degrees, in all APEC economies except Brunei Darussalam, Hong Kong, China and Papua New Guinea. Also, like many other industries in APEC, much of the growth in production is occurring in economies at earlier stages of development, particularly in China, where the energy efficiency of steel production is lower than in the most energy efficient economies.

For these reasons, many of the issues affecting the uptake and development of energy efficient technologies throughout APEC are evident in the steel industry.

In this chapter, the current status of steel production technologies and current trends in investment and innovation in the steel industry throughout APEC are summarised. This information is based on detailed analysis of existing infrastructure and current investment trends in the steel industry in the six focus economies.

Technologies used in iron and steel production

As in the electricity sector, steel makers in APEC economies have chosen to adopt a wide range of process routes and production technologies, which has resulted in large differences in the energy intensity of steel production across APEC. These processes range from the production of steel from iron ore in large integrated steelworks consisting of coke ovens, blast furnaces and oxygen converters, to the melting of recycled steel scrap, directly reduced iron or smelt reduced iron in smaller electric arc furnaces. These technologies are introduced below. More detailed descriptions of the technologies are contained in appendix B.

Integrated steel making is centred around the blast furnace, in which agglomerated (aggregated) iron ore, coke and a small amount of flux elements are combusted by hot gases generated as the descending coke and iron comes into contact with the upward moving hot blast air and other fuels. After being tapped from the bottom of the blast furnace while still molten, this reduced iron ore, or pig iron, along with a small portion of steel scrap, is transferred to a basic oxygen furnace, where oxygen is blown through the iron to further separate the carbon and other impurities from the metal. This process leaves molten steel, which is then poured into a ladle, where it can be blended with other materials, before being cast into shape. The steel is then continuously cast into slabs or other shapes before being passed through a hot rolling mill, where it is reheated and rolled to achieve a desired width and shape. After hot rolling, some steel products are ready for sale and use while other products require further treatment in a cold mill. In a cold mill, hot rolled coil is cleaned and further rolled to form either sheet or tinplate. Steel sheet can then be galvanised with zinc and/or other substances while tinplate is cleaned and coated with tin.

Because of the large number of individual processes involved in this production route, integrated steel mills are also significant energy users, consuming between 19 and 40 gigajoules of energy for each tonne of crude steel produced (de Beer, Worrell and Blok 1998). These differences in energy consumption are attributable to a number of factors, including the scale of the furnace, the extent to which waste heat from the blast furnace and coke ovens is captured and used to reduce growth in energy consumption elsewhere in the mill and the type of steel products being produced. Larger blast furnaces of around 3–5 million tonnes of iron a year capacity are much more energy efficient than smaller blast furnaces with capacities of less than 2 million tonnes of iron a year (Hismelt 2002).

Steel processing is also an important component of energy consumption in the steel industry, with hot strip mills typically consuming around 2 gigajoules for each tonne of steel processed, cold mills typically consuming between 2 and 3 gigajoules of energy for each tonne of steel processed and tinning and galvanising utilising between 1 and 2.5 gigajoules of energy for each tonne of steel processed (IISI 1998).

Electric arc furnace based minimills are generally smaller, simpler and more flexible operations than integrated steel mills, utilising fewer process steps to convert steel scrap and, in some cases, scrap substitutes such as direct reduced iron to final steel products. In this process, a charge of steel scrap and scrap substitutes and small amounts of lime are melted by an electric arc in the electric arc furnace. As with the basic oxygen furnace, oxygen can be passed through the electric arc furnace to accelerate the melting process. In modern ‘shaft’ furnaces, the metal charge is preheated in a separate vessel by furnace waste gases prior to being deposited in the furnace. After the charge has been melted and the slag removed, the molten steel is usually transferred to a secondary ladle for further refinement. After refinement, the steel is cast into either ingots, thick slabs (of greater than 150 millimetres in thickness) or thin slabs (under 50 millimetres thick). These slabs undergo some hot rolling before being sold and used.

Scrap based electric arc furnaces are much less energy intensive than blast furnace based integrated steel mills because they do not involve iron production. A modern electric arc furnace with scrap preheating can convert a charge of 100 per cent steel scrap to steel bars using around 5 gigajoules of energy for each tonne of crude steel produced (de Beer et al. 1998).

While most steel melted in electric arc furnaces is derived from 100 per cent steel scrap, there are some higher quality steel products for which the impurities contained in scrap are unacceptable and purer iron sources are required for these products to be produced in an electric arc furnace. For these products, direct reduced iron is used in the electric arc furnace. Direct reduction technologies facilitate the reduction of iron ore to a highly metallised product consisting of more than 90 per cent iron at elevated temperatures below the melting point of iron. They achieve this by reacting the carbon and oxides in agglomerated iron ore with reducing gases consisting of either hydrogen and carbon monoxide or just carbon monoxide, depending on whether natural gas or coal is used as the source of the reducing gas.

There are many direct reduction technologies, the most energy efficient of which can produce a tonne of direct reduced iron using around 11 gigajoules of energy (IISI 1998). The use of 100 per cent direct reduced iron in an electric arc furnace increases the energy consumption of steel production to at least 18.5 gigajoules of energy for each tonne of steel produced, meaning that energy consumption in an electric arc furnace using 100 per cent direct reduced iron is approximately equal to that in the most energy efficient blast furnace based integrated steel mills (de Beer et al. 1998).

Smelt reduction technologies represent another alternative iron production route. Smelt reduction technologies aim to provide a smaller scale, less capital intensive alternative to the blast furnace capable of producing pig iron from raw materials of lesser quality than those required for the blast furnace. Smelt reduction technologies generally split the iron making process in two by employing one vessel, known as the prereduction vessel, in which iron ore is partially reduced by hot waste gases originating from the second vessel, known as the smelt reduction vessel, in which the combustion of coal and oxygen produces enough heat to smelt the prereduced iron ore. The final iron product can be used in either an electric arc furnace or an oxygen furnace.

While there are many smelt reduction processes in development, only one, the Corex process, has been successfully commercialised at this stage. This process consumes significantly more energy for each tonne of hot iron produced than the most efficient blast furnace based integrated steel mill but, as the process also generates significant process waste gases that can be used to produce electricity for other energy users, the net energy consumption is estimated to be similar to that of the most efficient blast furnaces (de Beer et al. 1998). Currently, there are other smelt reduction processes in the early stages of commercialisation that are expected to consume less energy than the Corex process. These are discussed in more detail in appendix B.

Current status of iron and steel production technologies in APEC

Given the large differences in energy consumption between the major steel production routes described above, the energy intensity of steel production in each APEC economy is largely determined by the share of steel produced by blast furnace based integrated steel mills and the iron feedstock used in electric arc furnaces in each economy. In APEC, these characteristics are influenced by a range of factors, including natural resource endowments, energy prices, the ability of firms to raise investment capital and scrap supplies.

In APEC economies, as in the world as a whole, the blast furnace – basic oxygen furnace based integrated route is the main method of steel production, accounting for more than 60 per cent of the steel produced in APEC in 2002 (table 9). This reflects the fact that, until the advent of thin slab casting in 1989, the blast furnace – basic oxygen furnace route was the most economic method of producing high value flat steel products. Furthermore, given the ready availability of metallurgical coal and iron ore on world markets, the only real barrier to integrated steel making was the huge investment required by integrated steel works. This investment was, in some instances, offset by governments that were eager to establish steel industries in their economies. In 2002, the blast furnace – basic oxygen furnace route produced the majority of steel in Australia, Canada, Chile, China, Japan, Korea, the Russian Federation and Chinese Taipei and produced a significant share of steel in the United States. Integrated steel mak-

9 **Iron and steel production in APEC economies, by technology, 2002**

	Iron making			Steel making				Rolling
	Pig iron	DRI	Total	BF–BOF	EAF	Other	Total	Hot rolled
	Mt	Mt	Mt	Mt	Mt	Mt	Mt	Mt
Australia	6.1	1.0	7.1	6.2	1.4	0.0	7.5	4.8
Canada	8.7	0.2	8.8	9.5	6.5	0.0	16.0	15.1
Chile	1.0	0.0	1.0	1.0	0.3	0.0	1.3	1.2
China	169.1	0.2	169.3	130.6	29.0	22.1	181.7	194.0
Hong Kong, China	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Indonesia	0.0	1.4	1.4	0.0	2.5	0.0	2.5	3.8
Japan	81.0	0.0	81.0	78.5	29.2	0.0	107.7	98.1
Korea	26.6	0.0	26.6	24.9	20.5	0.0	45.4	46.2
Malaysia	0.0	1.1	1.1	0.0	4.7	0.0	4.7	4.7
Mexico	4.0	4.6	8.6	4.1	9.9	0.0	14.1	11.7
New Zealand	0.6	0.0	0.6	0.6	0.2	0.0	0.8	0.0
Peru	0.2	0.0	0.3	0.2	0.4	0.0	0.6	0.5
Philippines	0.0	0.0	0.0	0.0	0.4	0.0	0.4	1.2
Russia	46.3	2.9	49.2	36.7	8.9	14.2	59.8	46.8
Singapore	0.0	0.0	0.0	0.0	0.5	0.0	0.5	0.7
Chinese Taipei	10.2	0.0	10.2	10.5	7.7	0.0	18.2	25.3
Thailand	0.0	0.0	0.0	0.0	2.5	0.0	2.5	6.7
United States	40.2	0.5	40.7	45.5	46.1	0.0	91.6	90.7
Viet Nam	0.1	0.0	0.1	0.0	0.4	0.0	0.4	2.1
Total	394.0	11.9	405.9	348.3	171.1	36.3	555.6	553.8
Total (%)	*97.1*	*2.9*	*100.0*	*62.7*	*30.8*	*6.5*	*100.0*	*99.7*

Source: IISI (2004).

ing was also dominant in New Zealand, which relies on a kiln based process to produce iron from its iron sands rather than using a blast furnace to produce pig iron.

In 2002, electric arc furnaces were used to produce around 30 per cent of steel in APEC economies and were the dominant production method in Indonesia, Malaysia, Mexico, Peru, the Philippines, Singapore, Thailand, the United States and Viet Nam. In economies other than the United States, the high share of steel produced by electric arc furnaces results from the large scale and high capital costs of integrated steel mills, which required these economies to pursue alternative steel production routes. The specific routes chosen in these economies were influenced largely by their endowments of other steel making inputs. In Indonesia, Malaysia and Mexico, for example, limited steel scrap supplies and historically low natural gas costs have resulted in the use of natural gas based direct reduced iron technologies to produce much of the iron feedstock melted in their electric arc furnaces.

In the United States, the growing share of electric arc in total steel production has occurred as abundant scrap supplies have enabled electric arc furnaces to compete with blast furnace based integrated steel makers, which have struggled with high labor costs and competition from steel production in Japan and Korea for a number of years. While this trend was initially limited to lower value steel products that could be cheaply produced from steel scrap in electric arc furnaces, the commercialisation of thin slab casting in 1989 has resulted in electric arc furnace based minimills making inroads in some flat steel product markets. Although this trend is most evident in the United States, electric arc based minimills have been capturing market share from integrated steel producers in most APEC economies, except China, over the past decade.

Another characteristic of the iron and steel industry in APEC is that a number of economies, including Indonesia, the Philippines, Chinese Taipei, Thailand, Viet Nam and, to a lesser degree, China and Korea, operate rolling mills that are unassociated with domestic steel mills and roll more steel than they produce. This outcome occurs as a result of low rolling costs in these economies and, in some cases, domestic tariff barriers on finished steel products, which encourage steel makers to import semifinished products for processing. These finished products can then be sold in the domestic market without incurring the import tariff.

Energy efficiency of iron and steel production in APEC

In this section, energy consumption in the iron and steel industry in each APEC economy in 2002 is compared with the best practice energy consumption figures for each steel production route discussed in the preceding sections. This analysis shows that steel production tends to be more energy efficient in APEC economies such as Japan and Korea, where higher energy costs have provided incentives for steel makers to adopt energy efficient technologies. Steel production tends to be less energy efficient in economies such as China and the Russian Federation, where low energy costs, minimal exposure to international markets and, in some cases, poor financial performance have resulted in reduced investment in energy efficient technologies.

Because of the significant differences in the energy consumption of alternative steel production routes and for different steel products, analyses of energy efficiency in the steel industry typically compare the observed energy consumption in each economy with an estimated best practice energy consumption for the steel industry in that economy in that year. This estimate represents the energy that would have been consumed by the steel industry in that economy if it had produced the same mix of steel products with the same mix of iron and scrap feedstocks using the most energy efficient technology available (Price, Phylipsen and Worrell 2001). These estimates are typically based on specific energy consumption values as this measure provides a more accurate indication of the total amount of energy consumed in steel production. This is important in the steel industry because of the large share of energy consumed as electricity in electric arc furnaces (more detail on specific energy consumption is contained in the glossary at the front of this report). In this study, this methodology has been used to estimate the gap between actual energy consumption and best practice energy consumption in the steel industry throughout APEC in 2002 (see box 1).

Analysis of the data indicates that there is wide variation in the energy efficiency of steel production in APEC (figure 8). The highest energy efficiencies are recorded in economies, such as Japan and Korea, where the steel industry is based around large scale, modern technology and where high energy costs and stringent environmental standards have encouraged steel producers to make energy saving investments. The lowest energy efficiencies are recorded in the Russian Federation, China and Indonesia, where a larger share of production is undertaken in older, smaller scale furnaces and where low energy costs have reduced incentives for steel makers to invest in energy saving technologies.

These data also highlight the distinction between energy efficiency and energy intensity. While energy intensity is generally lower in economies

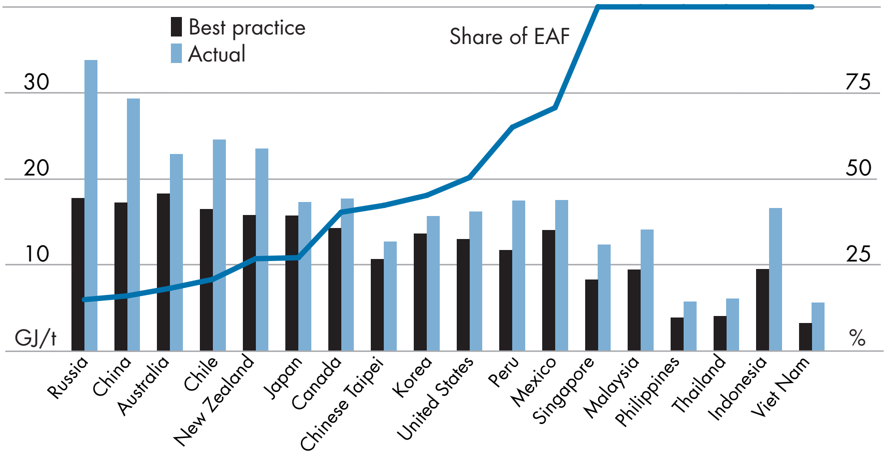
Box 1: **Measuring the gap between actual and best practice energy use in steel production**

For each APEC member economy the production of steel by each process in 2002 is multiplied by a best practice energy consumption figure for that process. For steel produced using the blast furnace – basic oxygen furnace route and other less efficient integrated routes (such as the open hearth furnace route) a best practice specific energy consumption factor of 19 gigajoules of energy for each tonne of steel is used (de Beer et al. 1998). The best practice specific energy consumption factor for scrap based electric arc furnaces is assumed to be 5 gigajoules of energy for each tonne of steel produced (de Beer et al. 1998). A best practice specific energy consumption factor of 10.9 gigajoules of energy is applied to each tonne of direct reduced iron produced in 2002 (IISI 1998). In economies where more steel is rolled than produced, a best practice specific energy consumption factor of 2.3 gigajoules of energy is applied to each tonne of steel rolled but not produced (Price, Phylipsen and Worrell 2001).

These estimates of best practice energy consumption for each process in each economy are added together for each economy. This summation produces an estimate of what the specific energy consumption of the steel industry in that economy would have been in 2002 had it been using the most energy efficient processes available. This estimate is then compared with an estimate of actual specific energy consumption in the iron and steel industry in 2002 using data taken from the IEA Extended Energy Balances. The difference in these numbers represents the gap between observed and best practice energy consumption in the steel industry in each economy in 2002.

In calculating the specific energy consumption, it is assumed that primary fuels are converted to electricity at an average thermal efficiency of 40 per cent in each economy. Where data are incomplete, energy consumption is estimated using data from economies with similar steel production. For easier comparison across economies, the data have been expressed in terms of specific energy consumption for each tonne of steel produced. For economies where more steel is rolled than produced, the data have been expressed as specific energy consumption for each tonne of steel rolled.

8 **Energy efficiency of iron and steel production in APEC, 2002**



where the share of steel produced in electric arc furnaces is higher, the gap between actual and best practice energy consumption is not necessarily lower in these economies. Also, the lowest energy intensities are recorded in economies where most of the steel rolled is not produced domestically.

Because rolling is much less energy intensive than steel production, the amount of energy consumed by the steel industry in these economies is also relatively low. However, the separation of steel production and rolling probably increases the overall energy intensity of the finished steel product as it needs to be transported to the rolling mill in an unrolled state as well as reheated before it is finally processed.

Technology in the iron and steel sector in the focus economies

Australia

In Australia, there are vast iron ore reserves in the north west of the continent and a relatively small and slowly growing domestic steel market located around population centres mostly in the south east. This has resulted in a large iron ore exporting industry and a small steel industry catering primarily to the domestic market. In 2002, Australia produced around 1 per cent of the world's steel but was the world's largest exporter of iron ore (ITR 2004). Throughout the 1990s, the integrated steel making sector in Australia underwent significant consolidation in response to increasing competition from foreign steel makers and domestic electric arc furnace based minimills. Also at that time, a desire on the part of both mining and steel making companies to add value to Australia's iron ore reserves was a driving force for the development and adoption of new iron making technologies in Australia. These developments have had a positive effect on the energy efficiency of the Australian steel industry.

Current status of technology

In 2002, Australia produced 7 million tonnes of iron and 7.5 million tonnes of steel (table 10). Around 80 per cent of this steel was produced by integrated steel makers using the blast furnace – basic oxygen furnace route and the rest was produced by small scrap based minimills using electric arc furnaces. This represents a change from 1992, when integrated steel mills produced more than 90 per cent of Australia's steel production. These changes have occurred as integrated steel mills in Australia have responded to increased competition from minimills and foreign producers by closing an integrated steel mill at Newcastle and replacing two small blast furnaces with one large blast furnace at Port Kembla. Another change from 1992 was the commencement of direct reduced iron production at the Port Hedland Finmet steel plant in 1999, which was placed on care and maintenance in May 2004 following an accident at the site (BHP Billiton 2004a,b). In 2002, the plant produced 1.2 million tonnes of direct reduced iron for export.

As a result of these changes, Australia now has two blast furnace based integrated steel mills and three electric arc based minimills (table 11). The integrated mill at Port Kembla can produce 5 million tonnes of steel a year while the integrated mill at Whyalla produces around 1 million tonnes of

10 Iron and steel production in Australia

	1992 a	1997 b	2002 b
	kt	kt	kt
Iron			
Pig iron	6 384	7 685	6 106
Direct reduced iron	0	0	1 229
Total	6 384	7 685	7 335
Steel			
Basic oxygen furnaces	6 369	7 731	6 156
Electric arc furnaces	525	1 100	1 371
Total	6 894	8 831	7 527
Continuous casting (%)	85.0	99.4	99.4

a IISI (1995). **b** IISI (2004) except direct reduced iron production ITR (2004).

11 Steel making capacity in Australia, 2003

Location	Type	Capacity
		kt
Port Kembla	Blast furnace – basic oxygen furnace	5 000
Whyalla	Blast furnace – basic oxygen furnace	1 200
Melbourne	Scrap based electric arc furnace	650
Sydney	Scrap based electric arc furnace	525
Newcastle	Scrap based electric arc furnace	250
Total		7 625

Source: ITR (2004).

steel a year (ITR 2004). The three minimills are all scrap based electric arc furnaces with capacities ranging from 250 000 tonnes to 650 000 tonnes a year (ITR 2004). All steel mills in Australia have continuous casting facilities and more than 99 per cent of Australia's steel is continuously cast, although none of this is cast as thin slabs (IISI 2004). In addition, there are seven rolling mills operating in Australia: two of these are cold rolling mills, four are hot rolling mills and one produces specialty steel products for the mining sectors (ITR 2004).

Because much of Australia's steel production capacity is relatively new, the Australian steel industry is relatively energy efficient. In 2002, the specific energy consumed for each tonne of steel produced in the industry was around 22.8 gigajoules. This is about 25 per cent higher than best practice energy intensity of 18.3 gigajoules of energy for each tonne of steel produced.

Investment trends in the steel sector

Over the past few years, a major driver of investment and innovation in the Australian steel industry has been the desire to convert Australia's substantial iron ore resources into value added products for the large and growing iron and steel markets in Asia. This driver has been fundamental to a number of major projects in the Australian iron and steel industry, including the continuing development of the Hismelt smelt reduction technology, the Finmet direct reduced iron plant and the giant Austeel project. As these projects are based on alternative iron making technologies, their commissioning could significantly change the technological composition of the Australian industry. However, given the cost overruns and recent placement on care and maintenance of the Finmet steel plant and the slow pace of development of the Austeel project, it is unclear how much impact these investments will have on the technological structure of the Australian steel industry.

Another major driver of investment in the Australian steel industry is the increasing regional demand for high quality flat products and stainless steels. This demand has encouraged the Port Kembla steel mill to invest in an additional 400 000 tonne capacity hot strip mill and has led to foreign interest in establishing stainless steel mills and rolling and coating operations in Australia (ITR 2004). Under the latter proposal, these rolling and coating operations may be complemented with electric arc furnace based minimills at a later date (www.protechsteel.com). This would be the first electric arc based minimill in Australia designed to produce high quality flat products.

Another project that could have important implications for the steel industry, both globally and in Australia, is the Castrip thin strip casting project in the United States. This project is a joint venture between Nucor of the United States, Bluescope Steel of Australia and IHI of Japan, which aims to commercialise the strip casting of carbon steels (Wechsler and Ferriola 2002). The strip caster is designed using technology codeveloped by Bluescope and IHI and is capable of casting 500 000 tonnes of carbon steel a year (Wechsler and Ferriola 2002).

Environmental policies are also having an impact on investment in the Australian iron and steel industry. In the past few years, flue gas desulfurisation facilities have been installed at the Hismelt steel plant and also at the Port Kembla integrated steel mill's sinter plant (Hismelt 2002; Bluescope Steel 2004). The Hismelt steel plant also incorporates specialised gas burners to reduce the nitrogen oxide emissions resulting from its natural gas combustion (Hismelt 2002).

The majority of these projects, particularly the Hismelt and Castrip projects and the proposed electric arc based minimills, imply increased energy efficiency and reduced greenhouse gas emissions intensity in the Australian steel industry. The Castrip project could potentially reduce the energy expended in hot rolling while the Hismelt process is less energy and emission intensive than blast furnace based pig iron production. Furthermore, carbon dioxide emissions from the Hismelt process could fall from around

1.9 million tonnes of carbon dioxide a tonne of pig iron to around 1.3 million tonnes of carbon dioxide a tonne of pig iron if an energy efficient direct reduction furnace is installed as the preheating vessel in stage two of the project (Hismelt 2002). However, the overall impact of these technologies could be limited by slow growth in domestic output, which could occur as new steel making capacity is commissioned closer to the more rapidly growing steel markets in Asia.

China

Since becoming the world's largest steel producer in 1996, China's steel industry has grown rapidly on the back of huge growth in domestic demand. Steel production in China reached 220 million tonnes of crude steel in 2003 and accounted for around 20 per cent of global steel production in that year. This growth is expected to continue over the next few years, with China's steel production forecast to reach between 330 and 400 million tonnes by 2010 (www.china-embassy.org; Deutsche Bank Research 2004).

China's steel industry is based around the use of its abundant coal reserves in integrated steel mills, many of which were originally constructed in the 1950s. Historically, these mills were inefficient energy users. However, the energy efficiency of China's steel industry has improved significantly in recent years as a result of the widespread adoption of continuous casting and the significant retrofitting and expansion of the older mills. While these investments have mainly aimed to increase output, particularly of flat steel products, which comprise a major portion of China's steel imports, a number of these projects have involved the adoption and demonstration of advanced steel making technologies. Most notable of these has been the Baoshan Corporation's (now Shanghai Baosteel) replication of Nippon Steel's technologically advanced, 10 million tonne a year capacity Kimitsu works, which began construction in the late 1970s (Otsuka, Liu and Murakami 1998). China's focus on large scale demonstration projects has led to the emergence of a small number of very large, efficient steel makers but left behind many small scale, less efficient producers. As a result there is still significant potential for efficiency improvements within the industry.

Current status of technology

Over the past few years, China's steel industry has recorded phenomenal growth, with output increasing from 81 million tonnes of crude steel in 1992 to 181.7 million tonnes in 2002 and 220 million tonnes in 2003 (table

12) (Danieli News 2004). Unlike in most parts of the world where new steel production capacity has tended to be electric arc furnace based mini-mills, growth in China's steel industry has been achieved through increased utilisation of the blast furnace – basic oxygen route, which doubled in output between 1997 and 2002. Another feature of this growth has been the rapid adoption of continuous casting technology by Chinese steel makers.

Continuous casting has increased from about 30 per cent of all steel produced in 1992 to 92 per cent in 2002. The adoption of continuous casting was part of a broader modernisation drive by the Chinese steel industry during the 1990s, when many large firms replaced aging blast furnaces, open hearth furnaces and ingot casters with large scale, modern blast furnaces and casting and rolling facilities.

This growth has had important effects on the composition of China's steel industry, with the emergence of some very large, efficient firms as well as a proliferation of smaller, less efficient firms. The large firms generally have good access to domestic and foreign capital, which enables them to invest in modern technology and take advantage of significant economies of scale. In 2003, China's largest ten steel firms produced more than a third of its steel production, with the top four firms producing more than 20 per cent (table 13). The market share of the

12 Iron and steel production in China

	1992	**1997**	**2002**
	Mt	Mt	Mt
Iron			
Pig iron	75.9	115.1	169.1
Direct reduced iron	0	0.1	0.2
Total	75.9	115.2	169.3
Steel			
Basic oxygen furnaces	38.5	63.5	130.6
Electric arc furnaces	17.6	19.1	29.0
Other	24.9	26.3	22.1
Total	80.9	108.9	181.7
Continuous casting (%)	30.0	60.7	92.4

Source: IISI (1995, 2004).

13 Top ten steel producers in China, 2003

Company	**Production**
	Mt
Shanghai Baosteel	20.2
Anshan Iron and Steel Group	9.6
Shougang Group	7.8
Wuhan Iron and Steel Group	6.9
Bengang Iron and Steel Group	5.9
Handan Iron and Steel Group	5.8
Shagang Group	5.6
Manshan Iron and Steel Group	5.6
Tangshan Iron and Steel Group	5.5
Valin Iron and Steel	5.1
Total	78.0

Source: ITR (2004).

largest firms is likely to increase in the coming years as China's major companies expand through capacity expansion and acquisition.

The smaller firms generally have poorer access to capital and are less able to invest in the advanced technologies. As a result, these firms do not always meet relevant environmental and product quality standards. In 2004, in an attempt to prevent overheating in the steel industry and limit the growth of smaller firms, the Chinese government introduced regulations to limit small firms' access to credit and land. Rising costs of electricity have also had more impact on small producers because larger producers often have their own power generation capacity or have negotiated long term contracts with electricity suppliers (Interfax 2004a). In addition, in 2004 Chinese authorities closed down more than 1000 small mills producing substandard steel products (Interfax 2004b). In late 2003, China's National Development and Reform Commission estimated that 70 per cent of China's iron and steel capacity failed to meet industrial policy entry standards (CISA 2004).

Although these developments have improved the energy efficiency of China's steel industry in recent years, China is still among the least energy efficient steel producers in APEC. In 2002, it is estimated that China consumed 29.3 gigajoules of energy for each tonne of steel produced. This is well above its best practice energy intensity of 17.3 gigajoules of energy for each tonne produced.

Investment trends in the steel sector

The major driver of investment in the Chinese steel industry at present is the need to expand production capacity to keep pace with domestic demand, particularly for high value flat products, such as steel sheet, which make up a large share of China's growing steel imports. The projects proposed range from large greenfield projects with major international steel firms to smaller projects adding additional blast furnace and basic oxygen furnace capacity to existing steel plants. Although some of these projects include the construction of electric arc furnaces, the overwhelming majority are integrated steel making projects based around the use of blast furnaces and basic oxygen furnaces.

Three major projects involve joint ventures between Chinese and foreign firms to produce high quality steel sheets for use in car manufacturing. These are the BX Steel Posco Cold Rolled Sheets project, which aims to produce 1.8 million tonnes of cold rolled steel sheet a year; the Baosteel–NSC/

Arcelor joint venture, which aims to produce 1.7 million tonnes of cold rolled and zinc galvanised steel; and the joint venture between Guangzhou Iron and Steel and Japan's JFE Holdings (Azom 2004; Shenzhen Daily 2004).

The need to modernise production processes is also a driver of investment for some firms. For example, the Hunan Xiangtan Iron and Steel Group has demolished three open hearth furnaces in the process of constructing new facilities capable of producing 5 million tonnes of steel a year (Metallurgy China 2004). However, the high rate of continuous casting in China's steel industry indicates that most projects specifically designed to modernise facilities have already been undertaken and that future modernisation of the industry is being achieved through capacity expansion.

In recognition of the growing competitiveness of China's steel industry, some firms have also exhibited interest in the adoption of potential leapfrogging technologies. For example, Laiwu Steel Group has signed a licence to develop a Hismelt iron making facility in China, if the technology is successfully commercialised in Australia (www.findarticles.com 2003). In addition, Korea's Posco intends to develop Finex facilities with Chinese companies, if its commercialisation in Korea is successful (Chosun Ilbo 2004).

The current wave of capacity expansion in China's steel industry has the potential to significantly improve energy efficiency in the industry by increasing the proportion of China's steel produced in large, modern facilities, particularly if guided by the principle of cleaner production. This improvement could be tempered by an increase in the share of China's steel produced by blast furnace based integrated steel mills rather than electric arc furnace based minimills. Alternative iron making technologies, particularly the smelt reduction technologies, appear well suited to China's resource base. Their role, however, will depend on the success of their commercialisation.

Korea

Despite its limited resource base and relatively small population, Korea's steel industry has grown rapidly in the past thirty years and in 2002 produced 45 million tonnes of crude steel, which made it the fifth largest steel producer in the world. The industry is based around the Pohang Iron and Steel Company (Posco), which through the adoption and development of best practice technologies has grown to become one of the largest and most efficient steel makers in the world, producing 25 million tonnes of crude steel in 2002, mostly through the blast furnace – basic oxygen furnace route. This efficiency, combined with Korea's strong environmental legislation and the relatively large share of its steel produced in scrap based electric arc furnaces, has made Korea's steel industry one of the world's most energy efficient.

The major driver of investment in Korea's steel industry is the need to remain internationally competitive in light of the growth of China's steel industry. Domestically, Korean firms have responded to this challenge by placing greater emphasis on the production of high value flat products, which China currently imports in significant quantities, and by investing in new technologies, such as the Finex smelt reduction process, which have the potential to lead to significant cost savings. Internationally, Korean firms have sought to establish a presence in emerging steel markets, such as China and India, by undertaking joint ventures with local companies requiring its technical expertise.

These developments are having opposing effects on the energy intensity of Korea's steel industry, with the additional cold rolling and galvanising carried out by Korean steel firms resulting in increased energy consumption, while the adoption and development of new technologies and other energy saving processes is reducing energy consumption for each tonne of steel produced.

Current status of technology

In 2002, more than half of Korea's steel was produced by Posco using the blast furnace – basic oxygen furnace route (table 14). In addition, Posco produced about 1.7 million tonnes of steel in its two electric arc furnaces and about 700 000 tonnes of pig iron using the Corex process. The rest of Korea's steel was produced by minimills using electric arc furnaces, which, despite Korea's relatively high scrap prices, expanded their output considerably from the 1980s to the mid 1990s by producing lower value long products. This expansion reflected the growing competitiveness of minimills in these markets and Posco's increasing focus on producing flat products.

This expansion has slowed since 1995, as the slower growth of Korea's manufacturing industries over this period has in turn reduced the growth of Korea's steel market (Park and Tcha 2000). This maturing of the economy was compounded by the Asian economic downturn of 1997, which led to reduced demand for Korea's steel and placed financial pressure on Korea's steel makers, most notably Hanbo steel, which was unable to finance investments and filed for bankruptcy in 1997 (JoongAng Daily, 24 September 2004).

In 2002, the Korean steel industry was one of the world's most energy efficient, with an average specific energy consumption of around 15.7 gigajoules for each tonne of steel produced. This is 15 per cent above the best practice energy consumption benchmark for Korea of 13.6 gigajoules of energy for each tonne of steel produced.

14 Iron and steel production in Korea

	1992	1997	2002
	Mt	Mt	Mt
Iron			
Pig iron	19.3	22.7	26.6
Direct reduced iron	0	0	0
Total	19.3	22.7	26.6
Steel			
Basic oxygen furnaces	19.6	24.2	24.9
Electric arc furnaces	8.5	18.3	20.5
Total	28.1	42.5	45.4
Continuous casting (%)	96.8	98.7	98.6

Source: IISI (1995, 2004).

Investment trends in the steel sector

At present, investment in the Korean steel industry is being driven by the need to remain internationally competitive in the light of the rapid growth of steel making capacity in China and by environmental considerations. To remain competitive in international steel markets, Korean steel makers have adopted both short term strategies, such as adjusting their output mix toward high value cold rolled and galvanised steel products, and longer term strategies, such as participating in joint ventures with companies in rapidly growing steel markets and investing in the development of new steel making technologies.

The trend toward producing more cold rolled and galvanised steel products has occurred as Korean steel makers have sought to capitalise on their technological expertise in these growing markets while also avoiding direct competition with Chinese steel makers in long product markets. In the past few years, Posco has purchased two galvanising lines while other firms, such as Seil Steel, have also expanded their steel galvanising capacity (Azom 2004; Posteel 2004). Their technological expertise in producing these products has also provided Korean steel makers with direct entry to the Chinese market by participating in joint ventures with Chinese companies. These ventures have included Posco's stainless steel project with Zhangjiagan

Steel and its cold rolled and galvanised sheet project with Benxi Iron and Steel Company as well as Dongkuk Steel's proposed joint venture in Brazil (Posco 2004; Korea Times 2004).

Korean steel makers have also placed emphasis on the development of new technologies, which have included the Finex smelt reduction iron making process and strip casting technology. Finex is a smelt reduction process using iron ore fines and non-coking coals to produce a product similar to pig iron without the need for coke making and sintering. This process was codeveloped by Posco and is based on the Corex process, which Posco adopted on a small scale in 1995. Posco is currently commercialising the Finex process by constructing a Finex steel plant capable of producing 1.5 million tonnes of iron a year as part of its current expansion program. After commercialising the technology, Posco intends to build Finex steel plants in emerging steel markets, such as China and India (Chosun Ilbo 2004).

Mexico

Mexico's iron and steel industry is one of the oldest in Latin America. With historically low natural gas costs and limited supplies of steel scrap, the industry is based around the utilisation of direct reduced iron in electric arc furnaces, which produce around two thirds of Mexico's steel. The Mexican steel company, Hylsamex, has played a key role in the development of direct reduced iron technology since the 1950s.

In recent years, the Mexican steel industry has undergone significant changes following its privatisation in the 1980s and 1990s and the commercialisation of thin slab casting technology in 1989. In the 1990s, these developments resulted in substantial growth in electric arc furnace capacity, as well as the closure of some previously government owned integrated steel making capacity. This replacement of old blast furnace based integrated steel making capacity with modern electric arc furnace based capacity significantly improved the energy efficiency of Mexico's steel industry. More recently, high natural gas and electricity prices have adversely impacted the industry, which has encouraged new research into alternative processes for the direct reduction of iron.

Current status of technology

In 2002, Mexico produced around 8.6 million tonnes of iron and 14 million tonnes of steel (table 15). Because of its historically low natural gas prices and the high capital costs of blast furnace based integrated steel making, more than 70 per cent of Mexico's steel production occurred in electric arc furnace based minimills using direct reduced iron or steel scrap as the primary feedstock. This represents a significant change since 1992, when electric arc furnace based minimills produced around 55 per cent of the 8.5 million tonnes of steel produced in Mexico and production of direct reduced iron was around half its 2002 level. However, Mexico's steel output in 2002 was still below the 15.6 million tonnes it produced in 2000. This fall in production is attributable to the large increases in Mexican gas and electricity prices in 2000, as well as reduced steel demand, both globally and domestically.

The large growth in Mexican steel production during the 1990s occurred as a result of a number of institutional and technological changes in the steel industry. The first of these was the privatisation of Mexico's state owned steel producers in 1991 and 1992, which attracted significant investment to the industry that led to the expansion and modernisation of a number of key firms. The second of these was the devaluation of the Mexican peso in December 1994, which greatly improved the competitiveness of Mexican steel in international markets, particularly the United States. Finally, the commercialisation of thin slab casting in electric arc furnace based minimills enabled Mexico's electric arc furnace based minimills, many of which were already utilising direct reduced iron, to start producing high quality flat products.

Notable investments in this period include the introduction of state of the art electric arc furnaces at Hylsa and Deacero and the expansion of steel and direct reduced iron production capacity at Ispat Imexsa, which became Mexico's largest steel maker in 1999 (Bagsarian 1999; www.steel-technology.com 2000; Sandoval and Kakaley 2001; Torres 2000).

Also important was the 1998 commercialisation of Hylsa's process for charging hot direct reduced iron to its electric arc furnaces, which signifi-

15 Iron and steel production in Mexico

	1992	**1997**	**2002**
	Mt	Mt	Mt
Iron			
Pig iron	3.4	4.5	4.0
Direct reduced iron	2.3	4.4	4.6
Total	5.7	6.9	8.6
Steel			
Blast furnaces	3.7	4.9	4.1
Electric arc furnaces	4.7	9.3	9.9
Total	8.5	14.2	14.0

Source: IISI (1995, 2004).

cantly reduced the melting time and energy requirement of its electric arc furnaces (Hylsa 1999).

These developments significantly improved the energy efficiency of Mexico's steel industry, with the gap between actual and best practice energy consumption estimated to have fallen from 47 per cent in 1990 to 34 per cent in 1996 (Ozawa et al. 2002). In 2002, Mexico consumed an estimated 17.5 gigajoules of energy for each tonne of steel it produced. This is around 25 per cent above its best practice energy consumption benchmark of 14.1 gigajoules of energy for each tonne of steel produced.

Investment trends in the steel sector

With many firms still confronted with significant debts from the capacity expansions of the 1990s, investment in the Mexican steel industry has slowed in recent years and little capacity expansion is planned for the near future. Much of the current investments are directed toward the increased processing of higher value flat steel products. Recent examples of this include the commissioning of a TOP lance and vacuum degasser at Ispat Imexsa in December 2004 and Hylsamex's expansion of its Galvak steel coating subsidiary (SMS Demag 2004a; Hylsamex 2003). In addition, Hylsamex is undertaking research and development aimed at developing a direct reduced iron process based on petroleum coke and on making direct reduced iron production more economical for smaller steel makers (Hylsamex 2003).

Over the longer term, it is expected that the Mexican steel industry will grow as the economy continues to develop and steel consumption per person rises from its current low levels. This growth should lead to continuing improvements in energy efficiency as old capacity, particularly old blast furnace based capacity, is replaced with modern electric arc furnace based capacity. Such a scenario would be particularly likely if natural gas prices in Mexico were to fall from their current high levels.

Thailand

From a small industry producing primarily long products for the construction industry and tin for the canning industry, Thailand's steel industry has grown strongly over the past decade in response to rapidly rising steel demand, particularly for high quality flat steel products used by its growing automotive and electrical appliance industries. However, as Thailand lacks both the natural resources and steel scrap supply used in steel making, the industry has evolved around the processing of imported steel. As a result, Thailand's production of hot rolled coil significantly exceeds its production of crude steel, all of which is produced in electric arc furnaces.

Current status of technology

In 2002, Thailand's electric arc furnaces produced 2.5 million tonnes of steel and its hot rolling mills produced 6.7 million tonnes of rolled steel (table 16). This represents a significant increase on 1992, when Thailand produced 0.9 million tonnes of steel and rolled 1.9 million tonnes. This increase occurred in response to the rapid steel demand growth associated with Thailand's high economic growth rates in the years prior to the Asian economic downturn of the late 1990s.

This period of growth began in 1994, with the commissioning of Sahaviriya Steel Industry's rolling mill capable of producing 1.8 million tonnes of hot rolled coil a year from imported steel slabs (Higashi 1996). This growth was further spurred on in November 1994, when the government overturned the ten year moratorium on new hot rolled capacity that it had introduced in 1989 to facilitate the Sahaviriya development (Higashi 1996). The next five years featured the commissioning of electric arc furnaces with combined capacity of 3.3 million tonnes of steel a year and four cold rolling mills, three of which were joint ventures with leading international steel companies (Higashi 1996).

This period of growth ended with the Asian financial downturn, which placed significant financial pressure on these recent investments, particularly those without international support. A notable example is the electric arc furnace based Nakornthai Strip Mill, which after being commissioned in 1997 was shut down in December 1998 and did not resume operations until December 2003 (Steel Week 2003; SMS Demag 2003b). Another

16 Iron and steel production in Thailand

	1992	1997	2002
	kt	kt	kt
Iron			
Pig iron	2	0	0
Direct reduced iron	0	0	0
Total	2	0	0
Steel			
Blast furnaces	0	0	0
Electric arc furnaces	929	2101	2538
Other	0	0	0
Total	929	2101	2538
Hot rolled steel products	1921	3516	6746

Source: IISI (1995, 2004).

project that was curtailed by the Asian downturn was an integrated steel works capable of producing 3.8 million tonnes of pig iron and 3 million tonnes of crude steel, that was to have been commissioned in 2000 (Tse 1998). This project would have played an important role in reducing the dependence of Thailand's steel industry on imported steel slabs.

These investments have resulted in the Thai steel industry having a relatively large share of modern, energy efficient equipment. As a result, the Thai steel industry is relatively energy efficient, with its specific energy consumption in 2002 of approximately 6 gigajoules of energy for each tonne of rolled steel being close to its best practise energy consumption benchmark of around 4 gigajoules a tonne. As discussed earlier, this low energy intensity reflects the large share of steel that is rolled in Thailand but produced elsewhere.

Investment trends in the steel sector

With the effects of the Asian economic downturn largely over, investment in the Thai steel industry is increasing in anticipation of strong future growth in steel consumption, both in Thailand and throughout Asia. These investments include expansions in hot and cold rolling capacity, recommissioning of plants closed during the Asian economic downturn and renewed efforts to introduce large scale integrated steel making facilities in Thailand. These investments are geared toward further developing Thailand's steel industry toward the production of high value flat steel products for its growing manufacturing industries, as well as reducing steel imports.

In December 2004, Sahavariyia Steel expanded its hot rolling capacity from 2.4 million tonnes a year to 4 million tonnes a year (ISIT 2004). This expansion is potentially part of a much larger expansion, in which Sahaviriya Steel would commission integrated steel making capacity capable of producing 30 million tonnes of steel a year by 2020 (The Nation 2004). At present, financing for the US$12 billion project, including the possibility of government support, has not been finalised and it is uncertain whether it will proceed (The Nation 2004). Reflecting the desire of Thai firms for integrated steel making capacity, G Steel has also sought approval for an iron smelting plant (Taipei Times 2004).

In another investment aimed at expanding Thailand's cold rolling capacity, Bluescope steel recently approved the installation of a second metallic coating line at the Map Ta Phut steel plant (Bluescope Steel 2004).

These investment projects could significantly change the structure of Thailand's steel industry and, as a result, could have large effects on its energy intensity. The commissioning of large scale blast furnace – basic oxygen furnace capacity, for example, would result in a large increase in the energy intensity of Thailand's steel industry.

The trend toward increased production of hot and cold rolled coil is also likely to lead to small increases in the amount of energy consumed for each tone of steel rolled. On the other hand, the introduction of modern electric arc furnace capacity could improve the energy efficiency of Thailand's steel industry by replacing older equipment and by enabling a greater share of Thailand's steel to undergo rolling on site.

United States

With its large reserves of coal and iron ore, as well as its huge domestic market, the US steel industry was among the largest in the world for much of the twentieth century, with production peaking at 136 million tonnes of steel in 1973 (IISI 1974).

Despite having undergone significant restructuring in recent years, the US steel industry is still the third largest in the world, producing 91.6 million tonnes of steel in 2002. This restructuring has occurred as many of the older blast furnace based integrated steel mills have struggled to compete with lower cost producers elsewhere in the world and with lower cost electric arc furnace based minimills in the domestic market. As a result, many steel makers have declared bankruptcy and much of the old blast furnace based integrated steel making capacity has either been absorbed into other companies or retired. At the same time, there has been substantial growth in electric arc furnace based capacity, which now account for the majority of steel production in the United States.

The rapid growth in electric arc furnace based minimills in the United States in recent years has placed the United States at the forefront of technology development in this sector. Of particular importance for this growth was the commercialisation of thin slab casting in the United States, which provided electric arc furnace based minimills with access to the high value added flat steel products market and further stimulated the growth of electric arc furnace based minimills in the United States. The success of this commercialisation has triggered further investment and innovation in the production of high value flat products using electric arc furnaces. One area of innovation has been in the production of direct reduced iron, particularly the development of new coal based direct reduction processes. A second area of innovation has been in the commercialisation of strip casting technology, which is presently under way in the United States.

Current status of technology

In 2002, the United States produced more than 40 million tonnes of iron and 91 million tonnes of steel (table 17). Around 46 million tonnes of this steel was produced in minimills using electric arc furnaces while the rest was produced using the blast furnace route. This represents a change from 1992 when more than 60 per cent of the United States' steel production was produced using blast furnace based integrated steel mills and electric arc furnace based minimills produced 32 million tonnes of steel. This change occurred as new electric arc furnace based minimills were commissioned to produce high quality flat steel products traditionally produced by blast furnace based integrated steel mills. In response to the growing competitiveness of electric arc furnaces, blast furnace based integrated steel producers in the United States have undergone significant consolidation and have also reoriented their production toward higher valued flat steel products.

17 Iron and steel production in the United States

	1992	1997	2002
	Mt	Mt	Mt
Iron			
Pig iron	47.4	49.6	40.2
Direct reduced iron	0.4	0.5	0.5
Total	47.8	50.1	40.7
Steel			
Blast furnaces	52.3	55.4	45.5
Electric arc furnaces	32.0	43.1	46.1
Total	84.3	98.5	91.6
Continuous casting (%)	79.3	94.7	97.2

Source: IISI (1995, 2004).

As a result of the persistent difficulties in the blast furnace based integrated steel making sector, the uptake of continuous casting in the United States occurred at a moderate speed. In 1992 the continuous casting ratio was about 80 per cent, which was much lower than in other developed economies, such as Japan and Korea. However, by 2002, ingot casting had been almost completely replaced by continuous casting.

By 2002, industry restructuring had significantly improved the energy efficiency of steel production in the United States as some older, less energy efficient blast furnace based integrated steel making capacity has been replaced with modern electric arc furnace capacity. However, because many of the restructured firms have not had the resources to modernise their equipment, much of the blast furnace based integrated capacity in 2002 was still consuming significantly more energy than best practice capacity. As a result, specific energy consumption for each tonne of steel produced in the United States in 2002 was estimated at 16.3 gigajoules of energy, which was above its estimated best practice energy intensity benchmark of 13 gigajoules of energy for each tonne of steel produced.

Investment trends in the steel sector

Investment in the United States steel industry is being driven by the ongoing restructuring of the blast furnace based integrated steel mills and the continued improvement in competitiveness of electric arc furnace minimills.

The restructuring of the blast furnace based integrated steel sector is proceeding as new steel companies, such as the International Steel Group, which is now the second largest integrated steel maker in the United States, acquire bankrupt older firms, such as Acme Steel, LTV Steel and Bethlehem Steel (International Steel Group 2004). As the new owners generally purchase these companies with reduced pension liabilities and have reached new agreements with steelworker's unions, these firms are returning to profit. If these profits continue, it is possible that equipment at these firms could be modernised, which could lead to reduced growth in energy consumption.

The trend toward the production of higher value added products by both high blast furnace based integrated still mills and electric arc furnace based minimills is also continuing. In the past few years, cold rolling mills have been introduced in many steel mills.

A third strategy being pursued by integrated steel makers in the United States is to establish operations in economies where production costs are lower and expected growth in steel demand is higher. Most notable of these have been US Steel's acquisitions in the Slovak Republic and Serbia, which have a combined production capacity of 7.4 million tonnes of steel a year (US Steel 2004).

Of potential importance for energy consumption in both the United States and elsewhere is the progressive commercialisation of thin strip casting technology at Nucor's Crawfordsville steel plant. This process has lower capital and operating costs than conventional hot strip casting technologies and also reduces energy consumption and greenhouse gas emissions from the casting process by about 90 per cent, or around 2 gigajoules of energy for each tonne of steel cast (Wechsler and Ferriola 2002).

New developments in direct reduced iron production also have the potential to reduce energy consumption in the United States' steel industry. For example, the Itmk3 process, capable of producing an iron product similar to pig iron from low grade iron ore and non coking coal for use in either oxygen furnaces or electric arc furnaces is currently under development (USDOE 2004b). A pilot project has already proven successful and plans are under way for the construction of the first commercial steel plant to begin in late 2005 in Minnesota (USDOE 2004b).

Despite the expected slow growth in steel demand in the United States, which has been relatively constant over the past decade, the energy efficiency of the United States' steel industry should continue to improve in the future as older blast furnace based integrated steel mills are replaced with new electric arc furnace based capacity. Furthermore, any modernisation of the recently restructured blast furnace based integrated steel mills is also likely to reduce energy consumption in the industry. The commercialisation of thin strip casting, if successful, could further reduce energy consumption in the steel industry. These improvements could be offset to some degree by the increased energy used in processing high value steel products and any increase in the use of direct reduced iron in electric arc furnaces.

Potential for energy savings in the iron and steel sector

In the APEC region there are substantial differences in the energy efficiency of steel production, even after accounting for structural issues such as the ratio of iron production to steel production. As in the electricity sector, these differences reflect both the demand for investment in energy conservation technologies, which is influenced by factors including energy prices, energy security concerns and environmental standards; and the average age of plant and equipment, which is influenced by factors including the level of an economy's development combined with its recent economic growth and the recent climate for investment in its energy consuming sectors. In APEC, the energy consumption of steel production is closest to best practice in economies such as Japan and Korea, which face high energy costs, and furthest from best practice in economies such as China and the Russian Federation, where substantial energy endowments have resulted in low energy costs and where investment in modern plant and equipment has at times been difficult.

Analysis of the current investment trends in the steel industry in APEC economies shows that technology transfer is taking place and that a range of new technologies are under development that could have potentially significant implications for energy consumption in the industry. In the steel industry, particular emphasis has been placed on the development of new casting technologies and alternative iron making technologies. However, while thin strip casting, if commercialised, is almost certain to reduce energy consumption in the steel industry, many of the alternative iron making technologies under development appear likely to have marginal, or even negative, impacts on energy consumption in the steel industry. This is because the main focus of these technologies is on using lower quality or widely available raw materials to produce steel while also reducing the capital costs of large scale, blast furnace based integrated steel production. As a result, the net effect of these technologies on energy consumption in the steel industry will depend on which of these technologies are commercialised.

Given the large disparities that exist in the energy efficiency of steel production across APEC, it appears that the transfer of best practice technologies to economies with less efficient steel industries is likely to have the most potential for improving energy efficiency in the steel industry in APEC. This is particularly likely given that most of the growth in steel production in APEC, and hence most of the market for new energy efficient steel production technologies, is located in economies where steel production is presently less energy efficient. However, in most economies except China, expansion in steel making capacity is not likely to be significant. To a certain extent, this limits the potential for improving the average energy efficiency of the steel making sector in an economy as new capacity will be brought on slowly.

A related point is that because steel production is growing more slowly in the most energy efficient steel producers, new technologies may only have a small impact on the energy efficiency of steel production in these economies. Instead, most of the improvement in energy efficiency in these economies is likely to occur through structural changes within the industry, such as increases in the share of steel produced in electric arc furnaces.

5

technology adoption in the energy sector

- Investment in power generation and steel making capacity often requires significant expenditure on capital that is long lived and has little salvage value. As such, investors may be exposed to considerable risk and uncertainty.

- The broad institutional settings in an economy will affect the viability of technology investments, with the costs of investment likely to be lower in economies with well developed capital markets and transparent legal structures.

- The decision to adopt a technology depends, in large part, on the relative capital and operating costs of alternative technologies. Government policy can have an impact on returns to investing through taxation regimes, emissions trading schemes, subsidies and compliance regulations.

- Continued emphasis on research into advanced technologies is needed to develop more advanced technologies that can improve the commercial and environmental performance of the energy and energy intensive sectors. Collaboration between APEC economies and coordinated research planning may lower the costs of research and development.

The importance of technology in the energy sector has been emphasised in this report because of its role in allowing APEC economies to achieve economic growth in a sustainable manner over the coming decades. The uptake of technological innovations in the energy sector has the potential to weaken the link between the expansion of energy consumption and greenhouse gas emissions. The preceding chapters have indicated that a wide range of energy technologies has been adopted in APEC economies over time, resulting in significant differences throughout the region in terms of thermal efficiency and environmental impacts of energy use. Some economies, such as Japan and Korea, have pursued the development and adoption of highly energy efficient technologies. However, in other APEC economies, old, outdated and inefficient power generation plants are still in use.

While the rate of transfer and adoption of energy efficient technologies in lesser developed economies is generally increasing, adoption rates remain low. If the potential for technology to reduce growth in energy consumption and greenhouse gas emissions is to be cost effectively realised, it is important to understand the leverage factors that drive capital investment in the energy sector through domestic and international policies. It is also important to understand the factors that drive the choice between energy technologies once the decision to invest has been made.

Drivers of investment and technology adoption are the focus in this chapter. Research and development in energy technologies is also considered in the chapter as this expands the set of technologies that are available to potential investors. In this discussion there is a strong focus on how government policy affects the drivers of technology adoption. Government policies are categorised into those that affect the institutional setting of an economy as a whole, and those that affect the energy sector in particular.

The role of uncertainty and risk when making investment decisions is also an important consideration. Uncertainty can be thought of in terms of being unable to predict certain states of nature such as electricity demand growth or future policy choices such as deregulation of the electricity sector. Risk is incurred when a financial decision is made and the return to that investment depends on which state of nature or policy choice actually eventuates. Uncertainty is an important consideration when deciding whether to invest, as well as when deciding what to invest in. This is also true when considering investment in research and development (R&D). The role of uncertainty and risk is explored as an integral part of technology development, transfer and adoption.

Technology transfer

The development of new technologies is undertaken in only a small number of economies worldwide, and in many instances much of this development is undertaken by a small number of companies. Most economies are, therefore, dependent on others for access to advanced technologies. Thus, the pattern of worldwide technical change is determined in large part by international technology transfer, often referred to as technology diffusion. The development of technology is important because it determines the pace at which the world's technology frontier may expand in the future. Technology diffusion is also important, as this will determine the rate of technological progress in the APEC region. A better understanding of technology transfer can provide insight into the likelihood that less technologically advanced economies will catch up to more advanced economies (Keller 2004).

The process of technology diffusion is often gradual. A number of conceptual models of technology diffusion and adoption have been proposed to explain the temporal pattern of this process. Some examples include life cycle models (Moore 1991) and diffusion models (Karshenas and Stoneman 1995; Geroski 2000). Within these models, the fraction of potential users that has adopted a new technology follows an ‘S’ shaped process over time, rising slowly at first, then entering a period of very rapid growth, followed by a slowdown in growth as the technology reaches maturity and most potential adopters have switched.

While these conceptual models can assist in identifying the key drivers of and impediments to technological change, it is important to place these frameworks into the context of the economy and the characteristics of the sector in which technological change is occurring. For example, a primary impediment to technology transfer in agriculture may be differences in the availability of factors such as labor or climate (Wichmann 1996).

The availability of labor in capital intensive sectors such as energy may not present a significant limitation if only a small pool of skilled resources is required and can be sourced. However, access to capital may be a constraint in developing economies. Further, for renewable energy technologies such as wind and solar power, climate may again be an important consideration. The benefits from adopting a technology will be different for developing economies for other reasons, most notably pressure for more rapid economic development and concern for the environment.

The drivers of change in consumer products or in diffuse industries such as agriculture, small manufacturing and the service industry are likely to differ from those in an industry characterised by the need for large scale investment that is often long lived and irreversible.

Investment in electricity generation and steel making capacity provide a good example of this type of investment as plant generally has a life cycle of more than thirty years, and investment is irreversible in the sense that the costs associated with plant installation cannot be recouped. For these sectors, adopting a new technology can be a high risk undertaking and minimising this risk requires considerable information both about the generic attributes of the technology, and about the details of the use of the technology in the particular application being considered. It takes time to develop this information generally, and to place it into the context of specific investment alternatives. Consequently, the process of information acquisition can impede the adoption of a new technology (Jaffe, Newell and Stavins 2003).

It is also important to recognise that technological change is seldom neutral. It can favor different factors of production, sectors of the economy and regions or economies with different resource endowments. For example, labor replacing technologies place downward pressure on labor demand and/or wages, and can impose adjustment costs on individuals who must relocate or retrain for new employment. The widespread adoption of energy saving technologies will have an impact on the demand for energy and the value of the existing stock of assets used in, for example, steel making. This can give rise to vested interests and political resistance to technological adoption (Canton, de Groot and Nahuis 1999). Identifying and addressing institutional requirements, information needs and policies that impede the adoption of more energy efficient technologies is an important task.

Factors affecting capital investment in the energy sector

APERC estimates that energy investments of up to US$4.4 trillion will be needed in the APEC region over the twenty years to 2020. These investments are needed to meet demand projections for electricity, coal, oil and gas production facilities and infrastructure. Of this, an estimated US$2 trillion is required for electricity generation and distribution. An additional US$205 billion could be needed to install equipment for controlling sulfur dioxide and nitrogen oxide emissions in coal fired power plants over the same period (APERC 2003). Required investment in steel making capacity is also significant as steel makers in the APEC region strive to remain competitive in the world market while meeting demand projections and stricter environmental standards.

While new capital investments provide major opportunities to adopt new technologies, refurbishment of existing capital is also important. There are a number of technologies that can be retrofitted to improve energy efficiency and reduce emissions of pollutants within an existing energy using plant.

This investment in refurbishment may be a natural part of a plant life cycle or in response to policy changes such as the tightening of greenhouse gas or other emission standards.

Factors driving the level of capital investment in the energy and energy intensive sectors include:

- expected demand growth and the need for increased capacity;
- the size and age structure of the existing capital stock, and the need to replace or refurbish existing capacity;
- government policies affecting the investment setting in an economy; and
- impediments or hurdles that tend to delay investment decisions.

Expected demand

The fundamental driver for energy investment is the rate of economic growth since it affects the rate of growth in demand for electric power and manufactured goods, including iron and steel, which in turn affects the pace at which investments are needed and will generate cash flow (APERC 2003). Demand growth in electricity and iron and steel is highly dependent on expectations of economic growth through the combined effects of factors such as rising household income, population growth, industrialisation and urbanisation. Projections of economic growth are presented for all APEC economies in the following chapter.

Developing economies tend to require more energy investment per unit of economic growth because they have proportionately larger requirements for investment in energy infrastructure. One reason for this is the transition from reliance on noncommercial energy sources, such as biomass that require little infrastructure, to commercial fuels such as coal, oil, gas and hydropower that require substantial infrastructure. At the same time, in developing economies, growth in urbanisation generates greater consumption of steel and electrical goods which, in turn leads to faster growth in energy consumption per unit of economic growth. Energy demand growth per unit of economic growth tends to be lower in developed economies because energy intensive industries such as manufacturing tend to make up a smaller part of the economy and significant infrastructure is often already in place (APERC 2003).

An unforeseen drop in demand may also affect the rate of investment in energy and energy intensive sectors. For example, regional or global recession may reduce electricity demand that will, in turn, reduce the need for investment in power generation capacity. In some instances, this reduction in demand may lead to the closure of uncompetitive power generation plant if the industry is forced to restructure.

Vintage effects

As existing infrastructure ages, new investment is needed to either refurbish or replace it. Therefore, the vintage, or age, of existing capital stock can be a determinant of investment and the rate of technology adoption. This is because the costs associated with existing steel or power generation plant increase with age as operational and maintenance costs increase. In short, it becomes more expensive to meet both financial and environmental performance standards as capital ages. Consequently, all other things being equal, an economy with an aging capital structure is more likely to make investments in new capital than one characterised by a relatively modern capital structure. This is important as capital stock in the power generation and iron and steel sectors is generally long lived and there can be a sizable efficiency gap between new capital equipment and the capital currently in use in the industry.

The age of existing capacity may also have an impact on refurbishment options. In older steel or power generation plants, it may not be economic to undertake major refurbishment as the life expectancy of the plant is too short. Further, it may be more difficult or impossible to retrofit older plant with newer technologies because of plant configuration or space limitations.

Government policy can directly influence the choice to invest in new capacity by changing the operating costs of existing steel or power generation plant through, for example, environmental standards or taxes. These policies tend to stimulate an increase in the turnover of capital stock and thus change emission and energy use profiles over time (Ruth, Davidsdottir and Amato 2004). This is important in the context of the age of existing capital as it brings forward the decision to refurbish or replace old capacity. Comprehensive data on the age and characteristics of existing capacity would provide useful insights into where future investment will generate the greatest returns.

Institutional settings and investment

The broad institutional settings in each economy will affect the viability of technology investments. Most notably, government policy will have a strong influence on interest rates and hence, the cost of capital. Lower interest rates will promote new investments and increase the rate at which existing steel or power generation plants are replaced or refurbished. This, in turn, will increase the rate of adoption of new technologies.

In general, the costs of investment in technology are likely to be lower in economies with well developed capital markets and transparent legal structures that provide strong protection for investors. Risks are higher in economies with unclear legal frameworks as investors have less certainty about future returns if certain events occurred, such as contract disputes.

Investment costs may also be lower in economies with governments that actively support investment and innovation through, for example, financial incentives. Trade barriers on plant components or fuel inputs, impediments to the mobilisation of financial capital and the migration of human capital, will also influence the level of investment in capacity. For example, rules and restrictions concerning foreign ownership of energy sector assets reduce a firms' control over the price received for its output, which, in turn, influences expected returns. Such restrictions on foreign ownership also reduce a firm's ability to protect the intellectual property embodied in a technology.

In developing economies, in particular, financial capital from foreign investors may reduce the burden on governments to fund capacity improvements and expansion. Foreign direct investment refers to a situation where a foreign owned or controlled company invests in an economy. The choice to invest in an economy will be highly dependent on the legal and institutional structures that govern such investment. The limited role of foreign direct investment in many developing APEC economies to date may be attributed to a complex and lengthy approval process for foreign investments, together with restrictions on foreign investment in many types of energy projects. Many APEC economies, including China, Mexico and Thailand, have removed impediments to foreign direct investment over recent years to facilitate investment from foreign firms (APERC 2003).

Foreign investment in the energy sector often takes the form of a joint venture where one or more foreign companies invest in a project with a domestic private entity for a mutually beneficial outcome. These companies may bring a range of attributes to the agreement, including financial capital, intellectual property rights to new technology or specific expertise. This is an important driver of technology transfer as foreign direct investment can reduce the cost of gaining access to or information on new technologies (Keller 2004). The migration of human capital can be especially important for the adoption of advanced technologies when resources are required from a relatively small pool of highly trained labor. The most likely source of these skills is from the economy that developed the technology.

Impediments to investment in energy technologies

Uncertainty about future returns means that there is an ‘option value’ associated with postponing new investment. The potential cost associated with making a poor and irreversible investment can be reduced by delaying an investment decision and waiting for improved information about likely project outcomes. This means that the expected return from an investment required to compensate investors may include not only the direct opportunity cost of capital, but also the costs associated with committing to an irreversible investment and losing the option to wait for better information on relative investment returns. To account for this uncertainty, purchasers use relatively high investment hurdle rates of return when evaluating energy investments (Jaffe et al. 2003).

The absence of appropriate institutions and unfavorable macroeconomic conditions can impede the potential for investment in new technology. High inflation, fluctuating exchange rates, inappropriate taxation regimes and incomplete pricing of materials, labor, energy and other inputs, as well as restrictive trade policies act as disincentives or impediments by lowering potential returns and significantly increasing the risk associated with investment.

New investments often require supporting infrastructure, such as gas pipelines, transport facilities or reliable electricity transmission networks, or human capital. Lack of knowledge, skills and practical experience within the local labor force can be an impediment to technology adoption in the energy sector if there are impediments to importing these skills. These linkages highlight the importance of coordinated policies to promote economic growth in developing economies.

Box 2: **Policy settings affecting investment in the focus economies**

China

In China, electricity prices are regulated through the National Development and Reform Commission. Over recent years, the government has shifted from a policy guaranteeing a fixed rate of return on power generation assets to providing lower cost electricity. In the case of the Zhonghua power project, one of China's largest, falling electricity prices have reduced investment returns. In 1998, the power purchase agreement for the project's Shiheng plant was set at 0.41 yuan/kWh (US$0.05/kWh). However, since negotiations began, power purchase agreements for other power generation plants in the project have been set at around 0.33 yuan/kWh (US $0.04/kWh). APERC analysis estimates that this would result in a reduction in the internal rate of return from about 6 per cent to less than 2 per cent (APERC 2003). These lower rates of return will limit China's scope for attracting foreign investment into the power sector. It also highlights the fact that shifts in government policy can represent major risks to investors more generally.

Korea

With a lack of indigenous energy resources, Korea is especially concerned with energy security. The government outlined a goal in its Ten Year Technology Development Plan (1997–2006) to reduce energy use by 10 per cent. In order to achieve this, it has implemented many policies to promote energy efficiency improvements. These include the promotion of voluntary agreements with large energy consuming enterprises, higher energy efficiency standards for electrical goods, removal of energy input subsidies, implementation of publicity campaigns to encourage energy conservation and the provision of low interest loans for the purchase of energy efficient equipment. While there are clear benefits associated with energy conservation, government energy policies directed at one sector will have an impact on others. Reducing growth in energy demand will slow investment, and the uptake of new technologies in the generation sector that may in the longer term have a greater impact on energy consumption.

United States

Deregulation of the electricity generation sector began around twenty years ago and has accelerated over the past decade, although the recent Californian electricity crisis has slowed this process in some states. A shortage of power generation capacity in California in 2000 revealed a number of disincentives to invest. These include restrictions on the use of long term contracts and spot market operating rules that left utilities highly vulnerable to short term price increases in times of high demand (IEA 2002a). These problems are being overcome and substantial capacity is now being built.

The investment environment in the energy sector is complex. Examples drawn from the focus economies can help to illustrate some of the important linkages between policy settings and highlight opportunities to encourage investment in new energy technologies (box 2).

Factors affecting the choice of technologies

Once a decision has been made to invest in new capital, investors must choose between competing technologies. There is a wide range of available energy saving and environmental technologies in the electricity and steel making sectors, ranging from new technologies where thermal efficiency is greater and improvements are still possible to more mature technologies where the level of efficiency is low and more or less fixed.

There are several factors that influence the value of a technology to individual steel or power generation plants or projects. While capital and operating costs are key considerations, there are other factors that may have a significant bearing on the optimal technology choice, including the reliability of the technology, supply security of the fuel feedstock and the ability of the technology to meet current and possible future environmental standards. The potential to update the technology can also be an important factor. Other factors include perceptions of risk of future revenue loss due, for example, to policy changes; construction time; and salvage value. Purchasers must, therefore, consider the tradeoffs in technology characteristics when choosing between technologies. There may be tradeoffs, for example, between capital costs and environmental performance, production capacity and operating costs, and conversion efficiencies and proven reliability.

For the purpose of this discussion, the factors affecting the choice of technologies are placed into four categories:

- The relative capital costs of alternative technologies that may include a return to the intellectual property rights embedded in that technology.
- The relative operating costs of alternative technologies determined, for example, by fuel costs and conversion efficiency.
- Government policies that have an impact on the relative returns to investing in alternative technologies including emissions trading schemes, subsidies, taxes and regulated compliance.
- Uncertainty and risk.

Capital and operating costs

Different technologies have different capital and operating cost structures. For example, renewable energy technologies are typically highly capital intensive and are associated with large initial setup costs. However, they tend to have low operation and fuel costs. On the other hand, fossil fuel fired electricity generation technologies are relatively less capital intensive but have high fuel costs (see appendix A for capital and electricity generation costs for selected technologies).

Given the differing cost structures between technologies, the expected cost of capital is an important determinant of technology choice. The cost of capital is the rate of interest, which is strongly influenced by government policy and usually includes a risk premium that reflects investment risk.

Lower costs of capital tend to make highly capital intensive technologies such as wind more cost competitive than highly fuel intensive technologies such as natural gas. In turn, natural gas combined cycle power generation plants have higher fuel costs and low capital costs compared with pulverised coal fired power generation plants, so NGCC power generation plants will tend to be favored when expected interest rates are high and disfavored when they are low. NGCC plants are also quicker to construct than many other power generation technologies including coal fired generation plants.

Further comparison of gas and coal fired power generation technologies is provided in appendix A.

Fuel costs for electricity generation vary considerably between technologies. For example, fuel costs can account for up to three quarters of total power generation costs for gas fired power generation plants but only half the power generation costs for coal. Consequently, equal percentage increases in the prices of different fuels for electricity generation would have a more serious impact on the financial performance of natural gas fired power generation plant than they would have on coal fired technologies (ACIL Tasman 2003).

Conversion efficiencies can be an important determinant of the cost competitiveness of alternative technologies. NGCC power generation plants can achieve up to 60 per cent efficiency in converting fuel to energy, while the highest rated pulverised coal fired power stations can only achieve efficiencies of between 33 and 48 per cent. This efficiency level needs to be taken into account when comparing fuel costs across technologies, since the higher efficiency of one technology option means that fewer units of fuel are required to obtain the same energy output.

Conversion efficiency may also vary according to location specific factors, such as fuel grade and differences in thermal properties of fossil fuels, as well as the ambient temperature at which coal and gas fired boilers are operating.

While operating costs of energy technologies are predominantly fuel costs, maintenance and other costs, which may include training and human capacity building associated with learning about a new technology, are also important. Once a technology has been adopted, learning effects associated with using the technology and associated efficiency improvements may reduce the cost of the technology. The cost related effects of learning by doing and market uptake are greater for newer technologies, and smaller for technologies that have been in use for some time (OECD 2003).

The application of the additional capacity will also influence the operating costs of the power generation plant. For example, in base load power generation, the unit is required to operate at a yearly capacity factor considerably higher than that of a unit generating peak load power. Accordingly, fuel costs, and hence conversion efficiencies, are of primary importance for base load operation. However, peak power requires the power generation plant to ramp electricity output up and down much more frequently — an application more suited to gas fired than coal fired power generation. The frequent ‘cycling’ of the unit leads to greater maintenance needs and more rapid performance degradation, which may shorten the economic life of the power generation plant (Ishii 2004).

Issues of comparative advantage may also influence technology choice. For example, a region with large reserves of iron ore is more likely to adopt blast furnace steel technology while an economy with little or no iron ore reserves might choose to adopt electric arc techniques using recycled scrap steel.

The location of infrastructure and environmental assets may also influence technology choices. For example, the cost effectiveness of solar technologies tends to be greater in remote locations or environmentally sensitive areas.

Government policy

Government policy can also influence the relative costs of different technologies. Taxes on emissions, fuel subsidies and regulated compliance to environmental or economic performance standards alter the cost structures of alternative technologies. There is a large body of literature exploring how government environmental policies affect technology adoption decisions (see Ishii 2004 for an overview). Emission standards may have an impact on a purchaser's fuel choice and/or technology choice.

The Clean Air Act Amendment that created a premium for 'clean burning' technologies in the United States, for example, has been shown to be a major driver behind the adoption of gas turbine technology for power generation. With natural gas turbines polluting less than generators driven by coal boilers, the Clean Air Amendments made natural gas turbines more cost competitive against coal based technologies because less emission control technologies were required to meet emission standards. However, given that there is relatively little variance in greenhouse gas emissions among different gas turbine technologies, the impact of an emission standard on the choice of those technologies is considered to be negligible (Ishii 2004).

Emission controls for carbon dioxide may, however, influence a power producer's choice of coal fired power generation technologies, as there is considerable variation in carbon dioxide emissions between technologies (see appendix A for data on carbon dioxide emissions for selected power generation technologies).

Broad energy sector policy can also influence the choice between alternative technologies. For example, for an independent power producer, a turbine with higher conversion efficiency not only translates into lower fuel costs but also provides a buffer against the risks associated with fuel cost volatility. A regulated utility may be much less exposed to this risk and, if so, would be less likely to adopt a technology where conversion efficiency came at the expense of a more beneficial characteristic (Ishii 2004).

Uncertainty and risk

Uncertainty is a factor that influences the choice between alternative technologies. Uncertainty about the security of supply of fuel stock and the price at which fuel can be purchased can be a factor when choosing between energy technologies. Typically, a natural comparative advantage will lie with technologies that utilise locally abundant factors intensively. However, in open markets, it is possible that imported fuel and material imports may be competitive. This will depend on several factors including the resource endowments of trading partners, world prices for different fuels and materials, any trade barriers affecting the supply and relative cost of imports, the distance from source supplier to destination, transport costs and the reliability of fuel and materials sourced from trading partners.

In situations where fuel prices are volatile, there can also be uncertainty associated with the benefits that a technology choice may bring. For example, for technologies designed to generate energy savings, there is the additional uncertainty that the economic value of such savings depends on future resource prices.

Uncertainty can be inherent in the technology itself in the sense that its newness means that users are not sure how it will perform in a particular application. Newly developed technologies are often associated with greater performance risk and less technical support. Benefits of new technologies, such as improved thermal efficiencies or environmental performance, may come at the opportunity cost of forgoing the reliability and support associated with an older but ‘proven’ technology. The cost of investing in higher risk technologies will be greater as investors will tend to demand a risk premium, increasing the cost of capital.

Demonstration power generation or steel plants are often used to prove that a technology will perform in a particular application. Pilot plants are constructed to demonstrate viability at a commercial scale to minimise the risk associated with their adoption. There are several examples of demonstration plants for both electricity generation and steel making technologies in the APEC region. These include an IGCC demonstration power generation plant in the United States and a Finex demonstration plant in Korea.

The successful demonstration of a technology can speed up the adoption process. For example, a hybrid wind/diesel plant was built in 1999 on the island of Xiao Qing Dao in China to demonstrate the use of renewable energy to offset diesel fuel use and provide environmentally friendly, low cost power. Much uncertainty surrounded both the ability of the wind/diesel plant to provide constant service at low cost, and the potential for demand for power in such a remote area to respond adequately to the provision of 24 hour power. The demonstration was successful and more hybrid wind/

diesel plants have been planned for offgrid villages in China (American Embassy in China 2002).

Generally, the state of technologies improves over time but the speed and extent of the improvement in technology is uncertain. This uncertainty associated with the rate of technological change also provides an incentive to postpone investment to limit the likelihood of regret. The choice to delay investment in energy efficiency saving technologies may, in some instances, lead to greater energy savings in the longer run as the adoption of superior technologies more than compensates for forgone short run energy savings (Dixit and Pindyck 1994). This is most likely to be true where the rate of technological progress is relatively rapid, and premature investment in a technology results in an inferior technology being ‘locked in’ (de Groot, Mulder and van Soest 2001).

In some instances, however, there may be an incentive to adopt a new technology quickly. For example, ‘breakthrough’ technologies may be adopted quickly where it is demonstrably better than an existing technology. Further, failure to move to this new technology may leave existing suppliers uncompetitive and vulnerable to new industry participants that enter on the new technology. In this instance, the adoption of the new technology by the incumbent suppliers may be a defensive strategy to retain market share.

All of the focus economies have polices designed to influence the choice of technologies. Motivations for these polices include economic development, energy security and concern for the environment. Examples of policies that influence technology choice in selected focus economies are presented in box 3. This is not intended to be an exhaustive list of such policies.

Technological innovation

Technological innovation is strongly linked to investment in research and development. A ‘technology menu’ can be thought of as a list of engineering processes that may be applied to produce outputs in a given sector. R&D expenditure can be characterised as an investment aimed at increasing this stock of applied knowledge. The impact of R&D expenditure may be direct, as with the development of near commercial technologies, or indirect, as with basic research that may not have a commercial impact until well into the future. R&D can also have benefits that spill over into other applications or sectors. R&D expenditure in the aeronautics sector, for example, has had considerable benefit for the development of gas turbines in the power generation sector (Ishii 2004).

Box 3: **Policy settings affecting technology choice in the focus economies**

Australia

The Mandatory Renewable Energy Target (MRET) scheme requires that an additional 9500 GWh of electricity be generated by eligible technologies in 2010 (AGO 2004b). In order for this to occur, energy retailers and large energy users are required to purchase a certain portion of their electricity from renewable sources. While mandatory targets will increase the costs of electricity generation, allowing retailers to source electricity generated from renewable sources in a competitive market will minimise these costs. However, policy investment in renewable energy sources may displace investment in more efficient coal and gas fired power generation.

Like many economies in APEC, Australia has imposed environmental standards on emissions from energy use. Industrial emissions of sulfur dioxide, nitrogen dioxide and carbon monoxide are limited under Section 51 of the Environmental Protection Act 1986. The National Environmental Protection Measure for Ambient Air Quality covers emissions of dusts and particulates (EPHC 2004). These standards have supported the adoption of emission control technologies which, in some instances, have been retrofitted to existing plant. In the steel industry, environmental legislation has contributed to the installation of flue gas desulfurisation facilities and low nitrogen oxide gas burners (to reduce the nitrous oxide emissions resulting from natural gas combustion) (Hismelt PER 2004). Another example is the retrofitting of flue gas desulfurisation facilities in the sinter plant at the Port Kembla steel mill (Bluescope Steel 2004).

China

The Chinese Government has introduced a tax on high sulfur coal and is developing gas distribution networks that will increase the supply of gas and improve the competitiveness of gas fired power generation technologies. The introduction of these policies will encourage China to develop manufacturing capabilities in gas technologies, including combined cycle gas turbines, which will further improve their operational and export performance. China's policy to promote manufacturing capabilities is an example of how broader policy objectives can drive technology adoption in the energy and energy intensive sectors and highlights the benefits of a coordinated policy approach (IEA 1999).

continued

Box 3: **Policy settings affecting technology choice in the focus economies**

continued

Mexico

Considerable effort has been made by the government to supply remote communities in Mexico with power. For communities without access to the grid, the government in partnership with the private sector, has implemented various electrification programs based on photovoltaic systems. An example of such a program is the Programa Nacional de Solidaridad, which is funded by a special budget for the electrification of areas not included in short term grid expansion plans. In addition to receiving funding, communities are informed about the mechanics of the solar systems and trained to operate and maintain the infrastructure. This is believed to be a key factor for the success of the program as it has promoted the uptake of photovoltaic as well as hybrid wind/photovoltaic systems across rural Mexico (WEC 1999).

Thailand

In 2003 a policy was introduced that requires all new fossil fuel fired electricity capacity to be associated with renewable capacity of at least 5 per cent of installed capacity from 2011 onwards (EGAT 2004). This would ensure that 630 megawatts of new power capacity between 2011 and 2015 will be renewable energy if planned total electricity capacity additions for that period come to fruition. Again, renewable energy targets may impose costs if renewable technologies are not cost competitive with fossil fuel technologies. However, directing investment in capacity toward renewable energy sources to meet new, rather than existing, demand will limit these costs because it will not displace existing generating capacity. Further, the significant lead time will allow investors to fully evaluate the best options to meet these targets.

United States

Emphasis has been placed on improving efficiency standards in recent decades (EIA 2004), with the National Appliance Energy Conservation Act of 1987 mandating minimum energy efficiency standards for several types of household appliances and equipment. This followed the earlier voluntary appliance efficiency targets of the Energy Policy and Conservation Act of 1975 and various state appliance efficiency standards (EIA 1995). The implementation of these policies and further raising of efficiency standards have contributed to falling energy intensity even though consumption of energy per person has increased over the same period.

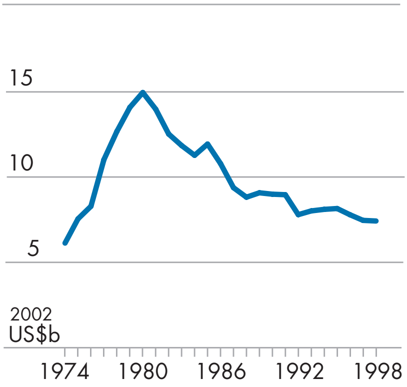
Innovation can occur in the application of existing technologies, often referred to as ‘learning by doing’. Ensuring that this acquired knowledge becomes part of the research capital can facilitate more rapid rates of technology development and adoption.

The payoff to research is inherently uncertain and the relatively high probability of failure must be offset by a correspondingly high payoff to a concept or prototype of a new technology. Development is directed at capturing the benefits of research — that is, turning research findings into a commercial or otherwise operational technology. Risk is still an important factor and the expected payoff to a successful research and development program needs to be high to attract investment, especially from the private sector.

Data show that annual expenditure on R&D directly relating to energy use has been falling in real terms in IEA economies since 1980 (figure 9; IEA 2004a). An explanation for this trend is that increasing competition in the energy sector, driven by the privatisation and liberalisation of energy related industries, has led to reductions in acceptable risk levels and increased levels of expected returns for energy research and development investments (Dooley, Luiten and Runci 1998). This trend is a concern for the APEC region as it may delay or limit the choice of more energy efficient technologies.

The diffuse nature of research benefits is often raised as a motivation for publicly funded research. But governments can influence R&D incentives by means other than direct expenditure. Environmental compliance regulations, emissions trading and other economic instruments will have an impact on returns to R&D and hence private sector investment. A key issue is that there are often long time lags associated with the signal of potential commercial returns from R&D and the development of technologies that exploit those returns. This highlights the importance of persistent signals for inducing technological change. Significant R&D investments are less

9 Research and development expenditure in IEA economies



likely when there is uncertainty about the duration of policy or other incentives (Weyant and Olavson 1999).

Technical and economic potential for innovation

Both the private and public sectors of an economy can undertake research and development. These sectors will, however, face different incentives to invest depending on how the benefits of innovation are derived. The potential for innovation in energy technologies is a function of a number of factors that influence the likelihood of a successful innovation, and the returns to that innovation. These include:

- the accumulated human capital generated from previous research, development and implementation of energy technologies;
- the potential of the application to be adopted in different sectors of the economy;
- cost savings arising from more efficient use of fuel and other inputs;
- reduced compliance costs of meeting environmental standards;
- the public benefits associated with the adoption of the technology — for example, the health benefits of improved air quality;
- the degree to which the technology frontier can be moved — for example, the gap between the current and physical limits to the efficiency of power generation from a given fuel source; and
- revenue from the sale or licensing of intellectual property once a technology has been successfully commercialised.

Some examples help to illustrate the potential synergies between these points. The extensive R&D effort on the electric motor, the internal combustion engine and hydrogen fuel cells all have applications in the electricity generation sector and this knowledge has been transferred at relatively low cost. Additionally, R&D expenditure on these ‘general purpose’ technologies can yield a return from a number of different applications of the technology (Bresnahan and Trajtenberg 1999).

There is a close relationship between energy consumption and emissions of greenhouse gases and other pollutants. Clearly the development of more thermally efficient technologies reduces the level of greenhouse gas emissions for a given level of output. The development of more efficient emission control technologies can lead to improved air quality, as well as reduce fuel costs if they improve the thermal efficiency of the power generation or steel production plant as a whole.

The returns to investment in R&D are highly dependent on the extent to which further research can close the gap between current performance and the theoretical limits of a technology. R&D in the power generation sector, for example, has to an extent moved away from improving the conversion efficiency of pulverised coal fired power generation plants toward technologies such as IGCC and hydrogen fuel cells that produce zero or fewer harmful greenhouse gas emissions. There is a greater return from investment in IGCC and hydrogen fuel cells as they are currently operating well below the theoretical limits of their potential. Similarly, there is little R&D expenditure on blast furnaces used in the steel making process because these are mature technologies near the frontier of potential efficiency and returns to investment are greater elsewhere.

Private sector expenditure on research and development

Private sector investment in research and development is primarily motivated by expected returns. This commercial interest gives rise to the hypothesis of 'price induced innovation' that was first suggested by Hicks (1932). Hicks noted that a change in the relative prices of the factors of production is itself a spur to invention and to invention of a particular kind — invention directed to economising the use of a factor that has become relatively expensive. For example, a sustained increase in fuel costs is itself an incentive to develop more fuel efficient technologies.

One implication of the induced innovation hypothesis is that the same drivers that affect levels of investment and the choice of technologies considered previously influence investment in R&D. For example, environmental and other policy interventions can create new incentives and constraints that have an impact on the process of R&D. The implementation of a carbon tax on fossil fuel use would increase the future costs of operating technologies that use more carbon intensive fossil fuels. This would again increase the potential financial gain from investing in R&D to accelerate the development of more fuel efficient technologies because, under the tax, fuels make up a greater proportion of total cost. In this way, R&D has the potential to augment the direct benefits of a policy change designed to promote the adoption of more efficient energy technologies (Popp 2004).

The drivers of induced technological development reflect the characteristics of demand and supply. At the same time, the development of new technologies has the potential to affect future market prices for both outputs and factors of production. These price changes determine who shares the ultimate benefits of R&D. For example, consumers benefit from the introduction of a more energy efficient generation technology to the extent that electricity producers pass on the savings through lower electricity prices. These relationships have implications for the impacts of market structure, regulation and government policy on R&D. This is particularly important in the APEC context as many economies still have monopolistic electricity supply sectors and there is considerable diversity in the degree of deregulation in the energy sector across the APEC region (Fairhead et al. 2002).

Price responsiveness or elasticity of demand is a key market characteristic as it reflects the ability of both consumers and producers to adjust their expenditure across a range of alternative goods and inputs. If power generators, for example, are unable to substitute between alternative fuels, their demand for a particular fuel will be non price responsive or inelastic. With less flexibility in their fuel choices, an increase in the relevant fuel price will have a larger impact on operating costs and there will be a greater incentive for technological innovation and adoption. This increase in costs to power generators can be partially offset if price increases can be passed on to electricity consumers. If consumers do not have alternative sources of electricity, their flexibility is reduced and producers can pass on a greater proportion of the increase in fuel costs. This, in turn, reduces the incentives for technological innovation and adoption. The low price responsiveness of final demand for energy will limit commercial incentives for R&D in the electricity sector.

The price responsiveness of supply also has an impact on the sharing of benefits of a successful innovation between producers and consumers. The proportion of the cost saving passed on to consumers will be greater the greater the price responsiveness or elasticity of supply. For example, consider an innovation that leads to greater conversion efficiencies in electricity generation. The subsequent increase in output will be greater the greater the price responsiveness of supply. The greater the increase in output the greater the reduction in electricity prices paid by consumers. In industry with large fixed investments, supply is usually not responsive to price in the short to medium term and the benefits of new cost saving technology will tend to be captured by those adopting the innovation.

The competitiveness of markets will also influence the incentives for technological innovation. In industries with less competitive structures, such as a monopoly, supply is less responsive to changes in output prices and input costs. As a consequence, a smaller proportion of the benefits of introducing a cost saving technology will be passed on to consumers and producers who adopt the innovation will capture more. Conversely, the more competitive an industry, the less incentive there is for innovation.

Market structure may also be important in reducing the spillover benefits of research and development, as there are fewer, if any, competitors in a highly regulated market in a position to take advantage of flow-on effects.

Governments have another important role in influencing returns to commercial investment in research and development. The ability of the private sector to capture the benefits of R&D depend, in large part, on the efficacy of legal frameworks for protecting intellectual property. Intellectual property rights in the form of patents, for example, allow those who invest in R&D to capture the benefits of a successful innovation by excluding competitors supplying that innovation. The greater the coverage, duration and the enforcement of these rights the greater the incentive to invest in the development of new energy efficient technologies. However, these rights mean that others must pay a higher price to obtain this new technology; hence, they can impede the rate of transfer and adoption.

Government expenditure on research and development

While commercial drivers of R&D play a critical role in the induced innovation literature, it should also be acknowledged that publicly funded research and development — for example, defence research or basic research funded in the university sector — has been a major driver of energy technology development (Weyant and Olavson 1999). While estimates differ from sector to sector, there is a body of evidence that suggests the social or overall economic rate of return for research and development exceeds the private return, providing an economic justification for governments' role in funding R&D activity (Nordhaus 2002).

There are two key reasons why the overall economic rate of return is greater than the private return to R&D. First, R&D can lead to benefits such as reduced pollution, that are nonprivate in nature in that they can be shared by the broader community without imposing additional costs. Second, R&D

can lead to spillover benefits to other industries and firms that generate economic gains from the technology that are not captured by those firms making the R&D investment. For these reasons, it is likely that there will be underinvestment in R&D by private firms.

Issues of comparative advantage may influence where governments direct R&D investment. In economies with large fossil fuel reserves, R&D may be focused on reducing or managing greenhouse gas emissions from using these fuels. Australia's effort into carbon geosequestration provides a good example of direct government investment in R&D. Successful R&D could lead to benefits in, for example, domestic energy production and potential trade in commodities such as coal.

Even in a public sector setting, commercial considerations can remain important. This is because increasingly, proposals for government R&D funding need to include measures of potential private sector benefits and are more favorably considered if total private sector benefits are expected to be high (Dooley et al. 1998). More generally, government R&D policies will have a significant influence on the magnitude and direction of R&D expenditure.

In the focus economies, research on advanced fossil fuel technologies is concentrated in the developed economies of Australia and the United States and, to a lesser extent, Korea. Research into nuclear power generation is an important component of research in the developing economies of China and Mexico. Nuclear power is also a significant area of research in Korea, reflecting its concerns about energy security. Renewable energy sources are a focus of research and development in all the focus economies. Examples of R&D activity in the energy sector in the focus economies are presented in box 4.

Technology investment and adoption in the APEC region

Government policies can influence the broad economic settings for investment in R&D and all aspects of the energy sector, as well as influence the choices between competing technologies. In general, policy settings that promote long term economic growth will underpin investment in human, industrial and natural capital and promote the development and adoption of more efficient technologies. The drivers and impediments to the adoption of technology presented in this chapter highlight the need to establish stable, transparent and predictable legal, fiscal, regulatory and trade regimes to facilitate investment.

In many APEC economies, energy industries are subject to extensive government involvement. This includes direct government ownership and management of energy resources and assets, as well as regulation of various aspects of energy supply and use. While regulatory reform agendas being proposed and implemented throughout the region vary, their common

Box 4: **Research and development activity in the energy sector in the focus economies**

Australia

The Australian Government spends a relatively high proportion of its energy R&D budget on fossil fuel technologies, with this share of R&D expenditure increasing between 1985 and 1999 (WEC 2001). State governments and universities also carry out fossil fuel research programs. The government's major climate change initiatives, introduced in the late 1990s, include subsidies, grants and other support measures for renewable energy sources, including vehicle conversion subsidies, grants for photovoltaic applications in households, green power investment, remote area power generation and greenhouse gas abatement programs (IEA 2001; AGO 2004b). Australia also participates in international research cooperation, especially in areas such as clean coal and carbon capture and storage programs.

In its recent White Paper, the Australian Government announced various new energy R&D programs with the goals of securing Australia's energy future and to minimise greenhouse gas emissions from the energy sector. The major initiative is funding to support industry led projects for large scale demonstration of low greenhouse gas emitting technologies that could reduce the cost of technologies with significant long term abatement potential. Other initiatives include funding for research and demonstration of smaller scale low emission technologies, solar and energy efficient technologies, other renewable technologies and advanced electricity storage systems (Department of Prime Minister and Cabinet 2004).

Private sector research is also conducted in the gasification of wet, brown coals for power generation, ultra clean coal technology and underground coal gasification (Coal21 2003).

continued

Box 4: **Research and development activity in the energy sector in the focus economies** *continued*

China

The National Natural Science Foundation of China program provides funding for energy conservation and emission reductions through the development of more efficient boilers, furnaces and gas turbines. The 973 program invests in internal combustion engines and sulfur reduction. It also has an energy saving initiative. The 863 program provides funding for clean coal and new energy sources such as fuel cells. The New and Renewable Energy Development Plan (1996–2010) aims to develop solar power, wind power, biomass, geothermal power, hydrogen technology and fuel cells (Rissanen and Tanaka 2003).

China also participates in joint cooperation R&D programs with the United States in areas such as renewables and efficient energy technology development and utilisation (Hsieh 1999).

Korea

Korea's Ten Year National Plan for Energy Technology Development (1997–2006) aims to promote the development of technologies in energy conservation, new and renewable energy and greenhouse gas emissions reductions. Government agencies such as the Ministry of Commerce, Industry and Energy have acknowledged that development of renewable energy sources has been poor in the past and funds have been allocated for R&D expenditure in thermal, solar photovoltaic, wind, small hydropower and bioenergy technologies.

With serious concerns associated with energy security, Korea has invested heavily in hydrogen technologies and fuel cells. Currently, several private companies and public research institutes are actively involved in fuel cell research and development. The target for 2012 is to introduce stationary fuel cells of up to 370 megawatts into the market (IEA 2002a).

Korea is also pursuing clean energy development with major areas of research that include clean coal utilisation technology, efficient use of fossil fuels, flue gas treatment technologies and energy recovery from waste resources (KIER 2003). Carbon dioxide separation and recovery from flue gases in fossil fuel electricity generating plants is another high priority.

The Government of Korea also contributes funding to nuclear power R&D. Research and development in nuclear power focuses on advanced nuclear reactors, monitoring the nuclear fuel cycle to avoid nuclear proliferation and other advanced nuclear technologies to secure nuclear safety.

continued

Box 4: **Research and development activity in the energy sector in the focus economies** *continued*

Mexico

The Mexican Electrical Research Institute undertakes energy R&D in nuclear power and renewable technologies such as geothermal power, grid connected photovoltaic systems and wind energy. Mexico also has various decentralised photovoltaic and solar programs that are supported by both the government and private industry. These aim to provide power to small villages that are not yet connected to the electricity grid (Mexican Electrical Research Institute 2004).

Thailand

The Government of Thailand contributes funding to the development of new technologies and the improvement of existing renewable energy as part of its initiative to promote renewable energy. Renewable technologies that have received considerable attention in terms of R&D include photovoltaic power and biomass.

Thailand is also considering developing fuel cell technology, which involves undertaking basic R&D and implementing demonstration projects on molten carbonate fuel cells and phosphoric acid fuel cells. In addition to funding domestic renewable energy R&D programs, Thailand is planning to participate in cooperative R&D programs with neighbouring economies (EPPO 2002).

United States

The United States invests significant funding into the development of advanced fossil fuel technologies, clean coal technologies, renewable energy, nuclear power and methods to decarbonise fossil fuels. An example is the $1.2 billion Hydrogen Fuel Initiative introduced in 2003, which aims to develop the technology needed for commercially viable hydrogen powered fuel cells.

Many of these developments will go toward the Department of Energy's overall goal for the industry — the Vision 21 Program that aims to revolutionise the power industry within the next fifteen years. This program builds on developments undertaken in other R&D programs, including low polluting combustion, gasification, high efficiency furnaces and heat exchangers, advanced gas turbines, fuel cells, and fuel synthesis. When these are coupled with carbon dioxide capture and recycling or sequestration, Vision 21 systems aim to release no net carbon dioxide emissions and minimise other environmental impacts (USDOE 2004c).

objective is to encourage more efficient energy supply and use (Fairhead et al. 2002). It is also important to ensure that the institutional arrangements within the energy and energy intensive industries are appropriate. For example, investment in the electricity generation sector may be impeded if the institutional setting governing investment in the transmission sector is inappropriate.

The movement away from price based regulation in the energy sector should help to promote private sector investment in research and development by allowing markets to ensure the benefits of successful innovations are appropriately shared by consumers and producers. However, government polices to promote competition in the energy sector reduce commercial incentives to invest in research and development as a greater share of the cost savings associated with improved energy efficiency is likely to be passed on to consumers in competitive markets.

Direct government expenditure on energy research is warranted given the spillover of both commercial and nonmarket or environmental benefits of increased energy efficiency. Governments can also increase the incentives for private sector expenditure through two mechanisms. The first are polices that alter the relative returns to existing and potential future technologies, such as a tax on emissions. The second is through the strengthening of the intellectual property rights embodied in a new technology.

However, pushing the pace of technological adoption can impose high costs. Given that investments in electricity generation and energy intensive manufacturing are large and have little or no salvage value, the level of a tax on greenhouse gas emissions, for example, would have to be large to bring forward a replacement decision if the power generation or steel plant has not reached the end of its useful economic life. Replacing existing capacity before the end of its economic life can lead to a significant writeoff of an economy's assets. Further, providing lead times before policy implementation allows firms or governments to acquire the information needed to make an investment in a new, more efficient technology.

Drivers that can affect the transfer of technologies to meet broader developmental and environmental goals can be competing and complementary. Stronger intellectual property rights may increase private investment in energy related research and development. At the same time, stronger intellectual property rights can increase the capital costs of transference. Further it may reduce the incentives for cooperative research planning and the sharing of intellectual capital and reduce the global benefits of these activities. Conversely, government expenditure on research may support the public benefits of, for example, improved energy efficiency leading to new technologies that can be transferred to other economies at a lower cost.

Given the wide range of avenues for government policy to influence technology development and adoption, it is clear that a coordinated policy approach is important in providing a clear set of incentives. For example, environment policies that hamper economic growth will reduce investment and ultimately the adoption of more efficient technologies in some sectors of the economy.

The time taken to acquire information when considering investment choices can impede the adoption of new technologies. Mechanisms to facilitate the dissemination of information may speed up the process of technology transfer and adoption. Some of those mechanisms have been discussed in this chapter and include foreign direct investment and coordinated R&D efforts. These mechanisms will be particularly important for the transfer of technologies from the innovating economy to developing economies and, as such, it may be important to have the support of both the private and public sector.

International cooperation will remain an important driver of technology transfer. China and the United States, for example, have entered into a collaborative agreement to facilitate technology transfer. The United States has made significant investment in advanced coal fuel electricity generation technologies, including IGCC, as well as nitrogen oxide and sulfur dioxide reduction technologies. In developing economies, in particular, lack of adequate funding has been an impediment to the adoption of IGCC technology. On the other hand, China is actively seeking financial assistance and international cooperation for commercialising advanced coal technologies. China and the United States developed a bilateral deal where the United States provided 70 per cent of the funds to establish the US/China Energy and Environment Technology Center (EETC) to enhance the competitiveness of US energy technologies and to facilitate technology transfer. To reach this goal, the EETC has undertaken research projects with participation from government, academia and industry to identify the applications of IGCC technology, factors affecting commercialisation of the technology and quantifying the global impact of its adoption (Hsieh 1999).

Collaboration and coordinated research planning is an area where there may be significant opportunities to increase the rate of development and uptake of more energy efficient technologies in both the generating and manufacturing sectors. The sharing of intellectual capital through collaboration and the avoidance of duplication will promote ideas and lower the costs of research and development. Further, collaboration is a means of spreading and, hence, managing the risks associated with a large scale research and development project. Coordinated research planning can make better use of the comparative research advantages in different economies. For example, fundamental research might be focused in developed economies where there is a critical mass of researchers and investment. Research supporting the transfer of a particular technology might be better conducted with developing economies with an interest in adopting that technology to their own specific circumstance. An example of the benefits of cooperative international research and development is provided in box 5.

Box 5: **Benefits of coordinated R&D in the development of strip casting**

Australian company BHP and Japanese machine builder Ishikawajima-Harima Heavy Industries (IHI) had an established business relationship when they started cooperative R&D activities relating to strip casting in the mid 1980s (Department of Science, Technology and Society 2001). Collaboration enabled these companies to split the large financial capital requirement and risk that is associated with an R&D investment of this kind. After much investment and testing, they reached the stage where they were able to build a full scale demonstration steel plant known as ‘Project M’. The Project M steel plant operated until 1999, perfecting the technology of casting low carbon steels into a variety of commercial products.

However, full commercial feasibility could not be verified until the process was implemented in a steel production plant and was able to demonstrate it could earn a financial return. BHP and IHI decided they could not achieve this on their own and needed another partner with experience, resources and commercial imperative to invest. They found this in the US owned company Nucor. Nucor joined the venture, bringing with it experience in implementing new technology in flat rolled steel production. Nucor started operating a steel plant in 2002 using the Castrip process and has since further improved the capability of the technology. The steel plant has recently surpassed the 100 000 tonnes cumulative production milestone and looks likely to be a successful implementation of a new technology (Nucor 2004).

Lastly, there are still a number of information shortfalls. First, there is little information on the age structure of existing capital stocks. Such information would be useful in research and development planning in that it could help identify when and where opportunities for adopting better technologies will occur. Second, it is important to understand the factors underlying technology investment and adoption in the context of each economy. Explaining changes in the geographic pattern of technology transfer reveal much about the process of technological adoption in developed versus developing economies (Keller 2004). This understanding will enable better targeting of policy drivers and mechanisms to facilitate technology adoption in the energy sectors of both developed and developing economies.

6

analytical framework and the reference case

- The potential economic and environmental benefits of new energy sector technologies in APEC economies are estimated in this study using ABARE's global trade and environment model (GTEM).

- The modeling in the report is based around a reference case, or 'business as usual' scenario, which projects the growth in energy consumption in APEC according to current expectations about the development of a number of variables. These variables include economic growth, the electricity fuel mix and the energy efficiency of new electricity generation and steel production capacity introduced throughout the region.

- In the reference case, total primary energy consumption in APEC is projected to grow by around 77 per cent, from 5513 million tonnes of oil equivalent (Mtoe) in 2002 to 9750 Mtoe in 2030. Fossil fuels are projected to retain their dominant share of APEC energy consumption, accounting for about 90 per cent of this growth.

- The growth in energy consumption is moderated to an extent by improvements in energy efficiency over the period. For example, efficiency improvements are projected to reduce the energy consumption and greenhouse gas emissions associated with natural gas fired electricity generation at 2030 by 25 per cent compared with the situation without the improvements.

- In forecasting the role of new technologies over the reference case, two key uncertainties relate to the pace of development of new technologies and the extent that these technologies are introduced throughout APEC.

- In recognition of these uncertainties, three alternative scenarios are defined in this study. The first of these is a high technology scenario, which analyses the implications of a number of more energy efficient electricity and steel production technologies that are not assumed to feature prominently in the reference case. The second scenario is one in which some of the institutional and policy constraints on the adoption of best practice technologies throughout the region are overcome more quickly than in the reference case. The third scenario is a combination of the first two, in which technologies are both developed and adopted more rapidly than in the reference case.

ABARE's global trade and environment model

The potential economic and environmental benefits of new energy sector technologies in APEC economies are estimated in this study using ABARE's global trade and environment model (GTEM). GTEM is a multiregion, multisector, dynamic general equilibrium model of the world economy. It is derived from the MEGABARE model (ABARE 1996) and the GTAP model (Hertel 1997).

GTEM is an appropriate framework for analysing complex issues such as those addressed in this study because it takes into account the interactions between different sectors of the economy and between economies through trade linkages. The model estimates the impacts of a range of policies or external shocks on key economic variables. These include productivity; the price of energy inputs to production; primary and final energy consumption; sectoral and regional output; trade and investment flows between regions; and regional income and expenditure levels.

GTEM includes a detailed representation of technological change and interfuel substitution in energy and energy intensive sectors. In GTEM, the 'technology bundle' approach is adopted to model electricity generation and iron and steel production, the two focus sectors in this study. Electricity can be generated from seven explicitly represented technologies: brown steaming coal, black steaming coal, petroleum, gas, nuclear, hydropower and other renewables based technologies. Substitution between technologies occurs in response to changes in their relative costs. This feature of GTEM is important for analysing the impacts of policies that affect the relative costs of energy inputs, such as those related to the introduction of new technologies, on the fuel mix for electricity generation.

Further, GTEM captures the substitution possibilities in iron and steel production between blast furnace and electric arc furnace based technologies. Where both technologies are capable of producing a given steel product, the iron and steel industry is able to substitute between these technologies in response to changes in their relative costs. In this way, GTEM restricts substitution possibilities to known technologies, thereby preventing technically infeasible combinations of inputs being chosen as model solutions.

In all other energy using sectors, GTEM allows substitution between fuels as well as between fuels and other primary factors of production — labor, capital and natural resources.

The model's database is also highly suited to an assessment of APEC's energy technology developments. The database separately identifies all but two APEC member economies and incorporates all of the major players in international energy markets. The model includes a high level of commodity disaggregation, including a detailed treatment of energy and energy intensive sectors.

GTEM also contains a sophisticated greenhouse gas emissions accounting framework. GTEM models emissions of the three major greenhouse gases — carbon dioxide, methane and nitrogen oxides. This allows the impacts of factors such as the uptake of advanced energy technologies on emissions of greenhouse gases to be estimated. Further information on GTEM and the model code is available on ABARE's web site (www.abareconomics.com).

Regional and sectoral aggregation

At its most disaggregated level, the version of GTEM used in this study consists of equations and data that describe the production, consumption, trade and investment behavior of representative producers and consumers in 68 regions across 56 sectors. In this project, the GTEM database has been aggregated to the 23 regions and 18 commodities that best capture the energy consumption, trade and environmental implications of new energy technologies in the APEC region (table 18).

Reference case

As a dynamic general equilibrium model, GTEM requires a reference case or a 'business as usual' scenario against which the impacts of alternative policies or external shocks can be measured. The reference case projects the growth in key variables in a region in the absence of any significant policy changes or external shocks. This means that the institutional and policy environment underlying the reference case reflects current institutional and policy settings and, over time, is adjusted to incorporate the impact of current policies and reforms with longer term dimensions.

In this study the reference case represents the likely outlook for economic activity, energy demand and emissions of greenhouse gases in APEC economies over the period to 2030, given current expectations about the uptake and development of electricity generation and iron and steel technologies over the period. These expectations are based on the current investment trends in the electricity and steel industries identified in chapters 3 and 4 as well as forecasts of technology development from a range of sources. These expectations inform the key assumptions underpinning the reference case, which include projections of economic growth and the mix and efficiency of technologies chosen to produce electricity and iron and steel in each economy.

18 GTEM reference case aggregation

Sectors	Regions
Brown coal	Australia
Black steaming coal	Canada
Coking coal	Chile
Oil	People's Republic of China
Gas	Hong Kong, China
Petroleum and coal products	Indonesia
Electricity	Japan
Iron and steel	Malaysia
Nonferrous metals	Mexico
Primary aluminium	New Zealand
Chemicals, rubber and plastics	Peru
Nonmetallic minerals	Philippines
Other mineral products	Republic of Korea
Manufacturing	Russian Federation
Trade and transport	Singapore
Services	Chinese Taipei
Agriculture	Thailand
Marine transport	United States
	Viet Nam
	Middle East
	Rest of OPEC
	European Union (25)
	Rest of world

Economic growth

In developing a reference case for APEC, assumptions have been made about the likely rates of economic growth over the projection period. The study uses historical growth rates for gross domestic product (GDP) from 1997 to 2003 (IMF 2004), while long term projections to 2030 are derived by fitting an ARIMA (autoregressive integrated moving average) forecasting model to the historical GDP data.

The GDP growth assumptions used in the reference case are shown in table 19. These assumptions project more rapid economic growth in lower income APEC economies at earlier stages of development, including China, Indonesia, and Viet Nam, and slower growth in higher income APEC economies, including Japan and the United States.

19 Average annual growth in real GDP, reference case

	2002–15	2015–30	2002–30
	%	%	%
Australia	3.4	3.2	3.3
Canada	3.1	2.8	2.9
Chile	4.4	3.9	4.2
China	7.3	5.0	6.1
Hong Kong, China	3.7	3.1	3.4
Indonesia	4.5	4.5	4.5
Japan	1.6	1.5	1.6
Korea	4.2	3.6	3.9
Malaysia	5.2	5.1	5.2
Mexico	3.4	4.1	3.8
New Zealand	3.2	3.1	3.1
Peru	3.8	3.0	3.4
Philippines	3.6	3.3	3.4
Russian Federation	5.1	4.6	4.8
Singapore	4.2	4.0	4.1
Chinese Taipei	4.1	4.0	4.1
Thailand	5.3	5.0	5.1
United States	3.4	3.0	3.2
Viet Nam	6.7	6.2	6.5

Electricity fuel shares

As the electricity sector is a major energy consumer in many APEC economies, the fuel mix in electricity generation is an important determinant of energy consumption (table 20). The fuel mix in electricity generation is also important in determining the types of new electricity generation capacity introduced in each economy and, hence, the potential impact of new technologies on the efficiency of electricity generation.

In this study, the shares of electricity produced by each fuel in each economy over the period to 2030 are determined exogenously using projections from government and other sources. These shares reflect a wide range of factors, including relative fuel prices, energy endowments and levels of development, as well as policy concerns about energy security and environmental pollution. For example, the share of natural gas in electricity generation is projected to increase relative to coal in many higher income economies. This is because it is assumed that the relatively low capital costs of natural gas turbines will ensure that natural gas fired capacity remains competitive for the provision of peak load electricity. This is expected to account for a greater proportion of electricity demand in higher income economies where economic growth is slower and base load demand is more adequately met by existing capacity.

On the other hand, it is projected that black steaming coal fired capacity will remain cost effective for base load capacity in many economies, as a result of its relatively low fuel costs. This is expected to result in increased shares of black steaming coal fired capacity in many lower income APEC economies, where a greater amount of new capacity is expected to be base load.

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Fuel shares in electricity generation, reference case

	Brown coal		Black coal		Oil	
	2002	2030	2002	2030	2002	2030
	%	%	%	%	%	
Australia	21.6	15.4	56.1	55.0	1.0	0.6
Canada	11.1	9.3	8.5	7.1	2.4	1.9
Chile	0.0	0.0	19.0	11.8	1.1	0.2
China	0.0	0.0	77.5	70.0	3.0	1.0
Hong Kong, China	0.0	0.0	63.6	65.0	0.4	0.4
Indonesia	0.0	0.0	39.6	55.4	23.2	7.2
Japan	0.0	0.0	26.5	24.3	13.2	7.7
Korea	0.0	0.0	39.7	37.0	9.5	0.5
Malaysia	0.6	0.2	5.4	32.4	9.3	0.2
Mexico	12.1	6.1	0.0	0.0	36.9	12.7
New Zealand	0.0	0.0	4.0	3.5	0.0	0.0
Peru	0.0	0.0	2.3	3.6	10.3	8.0
Philippines	0.0	0.0	33.2	40.5	13.0	4.4
Russian Federation	6.3	4.4	12.8	17.1	3.1	1.6
Singapore	0.0	0.0	0.0	0.0	39.6	13.6
Chinese Taipei	0.0	0.0	55.3	62.0	12.5	4.2
Thailand	15.3	2.0	1.1	16.0	2.6	0.2
United States	2.4	2.0	48.6	52.2	2.5	1.5
Viet Nam	0.0	0.0	13.6	12.9	12.2	1.8

	Natural gas		Nuclear		Other	
Australia	13.6	22.6	0.0	0.0	7.7	6.4
Canada	5.8	19.8	12.6	13.1	59.7	48.8
Chile	25.3	36.0	0.0	0.0	54.6	52.0
China	0.3	7.3	1.5	6.7	17.7	15.0
Hong Kong, China	35.7	34.3	0.0	0.0	0.3	0.3
Indonesia	22.0	24.8	0.0	0.0	15.2	12.6
Japan	22.3	27.6	26.9	31.6	11.0	8.9
Korea	12.7	13.7	36.2	45.0	1.9	3.8
Malaysia	77.3	58.3	0.0	0.0	7.4	8.9
Mexico	32.1	68.3	4.5	1.9	14.4	11.0
New Zealand	25.1	17.4	0.0	0.0	70.9	79.1
Peru	4.5	25.0	0.0	0.0	83.0	63.4
Philippines	18.0	32.0	0.0	0.0	35.8	23.2
Russian Federation	43.2	48.3	15.9	11.1	18.8	17.4
Singapore	58.3	81.5	0.0	0.0	2.1	4.9
Chinese Taipei	9.9	25.4	19.0	4.4	3.4	4.0
Thailand	72.2	73.8	0.0	0.0	8.7	8.0
United States	17.7	22.7	20.0	13.0	8.8	8.8
Viet Nam	23.2	32.6	0.0	0.0	51.0	52.7

Electricity efficiency assumptions

In addition to assumptions about the shares of electricity generation technologies in each economy, the reference case also contains assumptions about the change in efficiency of electricity generation over the period to 2030 (table 21). These assumptions capture the expected impact of investment in new electricity generation capacity on the average efficiency of electricity generation. They reflect the range of factors that influence the efficiency of new and existing power generation capacity in each economy. For existing capacity, these factors include the average age and initial efficiency of the capital stock as well as the way in which that stock has been maintained. For new power generation capacity, the factors affecting technology choice in each economy include capital and maintenance costs, fuel and other operating costs. As discussed in previous chapters, these costs can vary significantly with the institutional and policy settings in each economy.

21 Average annual growth in the efficiency of electricity generation, reference case, 2002–30

	Steaming coal					
	Brown	**Black**	**Oil**	**Natural gas**	**Nuclear**	**Other**
	%	%	%	%	%	%
Australia	0.32	0.39	0.14	0.92	–	0.83
Canada	0.44	0.22	0.09	1.00	0.92	0.92
Chile	–	0.26	0.36	0.26	–	0.68
China	–	0.56	0.13	1.26	1.77	1.77
Hong Kong, China	–	0.26	0.14	0.03	–	0.33
Indonesia	–	1.06	–0.09	–0.20	–	1.25
Japan	–	0.14	0.20	0.19	0.54	0.54
Korea	–	0.20	0.39	0.33	0.90	0.90
Malaysia	0.02	0.89	0.55	0.25	–	1.11
Mexico	0.19	–	0.28	0.81	0.82	0.82
New Zealand	–	0.28	0.28	0.14	–	0.81
Peru	–	0.35	0.28	0.85	–	0.54
Philippines	–	0.66	0.27	0.19	–	0.54
Russian Federation	1.08	1.65	0.40	1.71	2.56	2.56
Singapore	–	–	0.10	0.33	–	0.52
Chinese Taipei	–	0.58	0.24	0.37	1.24	1.24
Thailand	0.25	0.47	0.57	0.25	–	1.18
United States	0.56	0.36	0.08	0.75	1.09	1.09
Viet Nam	–	0.88	0.19	0.20	–	1.79

Note: – Occurs where economies do not use that technology.

For fossil fuel based technologies, comprising brown steaming coal, black steaming coal, oil and natural gas, the assumed thermal efficiency improvements in electricity generation in each economy are driven by changes in the capital stock over the reference case. As electricity output grows, it is assumed that the average thermal efficiency of electricity generation will change as old capacity is retired and new capacity is commissioned. Where it is expected that the electricity generated from a particular fossil fuel will fall over the period, it is assumed that thermal efficiency improvements will occur as the least efficient capacity is retired first.

To calculate the impact of these changes on the thermal efficiency of electricity generation by each fuel type in each economy over the reference case, it is necessary to make assumptions about the thermal efficiency of existing electricity generation capacity in 2002 and the average thermal efficiency of new capacity introduced between 2002 and 2030.

Assumptions about the initial efficiency of electricity generation capacity in each economy are based on analysis of the composition of existing electricity generation technologies using each fuel in each economy, as presented in chapter 3, as well as information contained in the 2002 and 2004 International Energy Agency World Energy Outlooks, and, for some economies expert consultations.

Assumptions about the average efficiency of new electricity generation capacity were based on further assumptions about the development and adoption of a number of electricity generation technologies in each economy over the reference case (table 22). These technologies include steam boilers, simple and combined cycle gas turbines and integrated combined cycle coal gasification. The development of these

22 Assumed maximum thermal efficiencies of electricity generation technologies introduced in the reference case

	2002	2030
	% LHV	% LHV
Brown steaming coal		
Steam boiler	37.0	41.0
IGCC	39.0	46.0
Black steaming coal		
Steam boiler	40.0	45.0
IGCC	43.0	52.0
Oil		
Simple cycle gas turbine	34.0	40.0
Steam boiler	40.0	45.0
Natural gas		
Simple cycle gas turbine	34.0	40.0
Combined cycle gas turbine	55.0	62.5

Source: Derived from IEA (2002a,b).

technologies over the reference case is based on the authors' judgment as well as the work of other forecasters, notably the International Energy Agency.

From these broad assumptions it is possible to calculate the average thermal efficiency of new electricity generation capacity, by fuel, in each of the focus economies over the reference case. When combined with information on the initial efficiency of electricity generation capacity in each economy and the growth of electricity generation, by fuel, over the reference case, these assumptions about new capacity enable the overall improvement in the efficiency of electricity generation, by fuel, in each economy to be calculated (table 23).

These data indicate that thermal efficiencies are initially highest in economies such as Japan and Korea, where high energy costs and serious concerns about energy security have encouraged investment in energy efficient technologies; and lowest in economies such as China and the Russian Federation, where incentives for energy conservation have been low and where the ability of firms to maintain or upgrade their capacity has at times been reduced.

The importance of environmental standards for electricity generation capacity is also evident in the efficiency of coal fired capacity, which is higher in high income APEC economies, where environmental standards are closely monitored, including Australia, Canada and the United States.

In the area of natural gas fired capacity, the average age of capacity is as important as environmental legislation in determining average thermal efficiency, with high efficiencies evident in economies where modern combined cycle turbines account for a large share of capacity. These economies include some lower income APEC economies where a significant amount of natural gas fired capacity is relatively new, including Indonesia, Thailand and Viet Nam.

The efficiency assumptions in the reference case reflect a business as usual approach to technology uptake in the electricity industry, in which economies that have most strongly pursued high levels of energy efficiency in the electricity sector, such as Japan and Korea, are assumed to introduce the most thermally efficient technologies over the period to 2030. This is most noticeable in the case of coal fired electricity generation, where it is

23 Assumed thermal efficiency of existing and new electricity generation capacity, reference case

	Brown steaming coal			Black steaming coal		
	2002	New/with.	2030	2002	New/with.	2030
	%	%	%	%	%	%
Australia	28.4	35.0	31.1	36.7	44.1	40.9
Canada	26.2	37.0	29.6	36.7	43.9	39.0
Chile	–	–	–	35.5	40.0	38.2
China	–	–	–	29.6	37.1	34.6
Hong Kong, China	–	–	–	39.5	44.1	42.5
Indonesia	–	–	–	27.7	38.8	37.2
Japan	–	–	–	41.1	46.3	42.8
Korea	–	–	–	41.7	45.6	44.0
Malaysia	26.0	37.0	26.1	30.0	38.8	38.5
Mexico	32.7	38.8	34.5	–	–	–
New Zealand	–	–	–	36.7	43.8	39.7
Peru	–	–	–	35.5	40.0	39.2
Philippines	–	–	–	30.0	38.8	36.1
Russian Federation	15.0	35.8	20.3	20.0	39.2	31.6
Singapore	–	–	–	–	–	–
Chinese Taipei	–	–	–	35.0	44.1	41.2
Thailand	30.0	28.0	32.2	34.0	38.8	38.7
United States	26.2	37.0	30.6	36.7	43.9	40.5
Viet Nam	–	–	–	29.1	38.8	37.2
	Oil			Natural gas		
Australia	33.5	38.9	34.8	35.0	48.8	45.3
Canada	35.4	38.9	36.3	34.8	48.2	46.0
Chile	33.7	29.0	37.3	43.0	47.0	46.3
China	24.7	20.0	25.6	32.7	46.5	46.4
Hong Kong, China	36.5	38.9	38.0	51.0	51.6	51.4
Indonesia	43.0	36.4	42.0	45.9	42.8	43.4
Japan	44.9	38.9	47.5	46.5	51.6	49.1
Korea	35.8	35.3	40.0	45.0	51.6	49.3
Malaysia	36.5	36.0	42.6	39.5	43.5	42.4
Mexico	36.3	28.0	39.2	36.0	47.0	45.1
New Zealand	33.5	38.9	36.2	45.0	51.1	46.8
Peru	33.7	38.1	36.4	36.6	47.0	46.4
Philippines	35.0	29.5	37.7	45.0	48.0	47.4
Russian Federation	18.0	11.1	20.1	17.1	36.7	27.5
Singapore	36.5	31.5	37.5	44.0	49.5	48.2
Chinese Taipei	36.5	30.5	39.0	43.5	49.0	48.2
Thailand	36.5	34.0	42.8	44.0	48.0	47.2
United States	35.4	28.0	36.2	34.8	48.2	42.9
Viet Nam	36.5	31.2	38.5	41.2	43.9	43.6

Note: – Occurs where economies do not use that technology. ‘New/with.’ refers to the average thermal efficiency of capacity added or withdrawn from service between 2002 and 2030.

assumed that integrated gasification combined cycle coal power generation plant accounts for a significant share of new coal capacity in these economies but only a small share of new capacity in economies where incentives for energy conservation are lower.

Another feature of these assumptions is the significant improvements in thermal efficiencies forecast for economies that have relatively low initial efficiencies. This is projected to reduce the efficiency gap between the low efficiency economies and the most thermally efficient electricity generators. This catchup is projected to occur most strongly in natural gas fired power generation as a result of the expected widespread introduction of combined cycle gas turbines, albeit at slightly different efficiency levels, in all APEC economies.

Technology shares in iron and steel production

Given the significant differences in the energy intensity of alternative process routes in the iron and steel industry, the reference case also contains assumptions on the shares of steel produced by blast furnace based integrated steel mills and electric arc furnace based minimills in each economy (table 24).

These shares are based on data published by the International Iron and Steel Institute and ABARE forecasts. They reflect a continuation of the recent trend toward increased steel production by electric arc furnace based minimills in the majority of steel making economies, with the notable exceptions of China and Japan. Underlying this assumption is the expectation that the huge capital costs of new integrated steel making capacity and the oversupply of capacity in most economies will limit investment in new integrated steel making capacity to economies where demand growth is sufficient to warrant the large production scale necessary for competitive steel costs, such as China.

In economies where the integrated sector is well established but steel demand growth is slower, such as Japan and Korea, it is expected that investment in the sector will be limited to the maintenance and expansion of existing capacity. It is also expected that the supply of steel scrap in APEC will continue to grow, particularly in lower and middle income APEC economies, as more of the steel currently in use is retired and as more emphasis is placed on scrap collection.

24 Shares of steel produced by each process route, reference case

	Blast furnace – basic oxygen furnace route			Electric arc furnace route		
	2002	2015	2030	2002	2015	2030
	%	%	%	%	%	%
Australia	81.8	80.4	79.8	18.2	19.6	20.3
Canada	59.4	52.4	52.4	40.6	47.6	47.7
Chile	79.2	69.5	64.8	20.8	30.5	35.3
China	84.0	83.4	81.9	16.0	16.6	18.1
Hong Kong, China	–	–	–	–	–	–
Indonesia	0.0	0.0	0.0	100.0	100.0	100.0
Japan	72.9	74.5	75.2	27.1	25.5	24.9
Korea	54.8	52.4	51.2	45.2	47.6	48.8
Malaysia	0.0	0.0	0.0	100.0	100.0	100.0
Mexico	29.3	20.6	17.2	70.7	79.4	82.8
New Zealand	73.1	61.7	56.5	26.9	38.3	43.5
Peru	35.0	25.3	21.3	65.0	74.7	78.7
Philippines	0.0	0.0	0.0	100.0	100.0	100.0
Russian Federation	85.1	82.4	79.3	14.9	17.6	20.7
Singapore	0.0	0.0	0.0	100.0	100.0	100.0
Chinese Taipei	57.7	57.9	57.8	42.3	42.2	42.2
Thailand	0.0	0.0	0.0	100.0	100.0	100.0
United States	49.6	47.1	46.1	50.4	52.9	54.0
Viet Nam	0.0	0.0	0.0	100.0	100.0	100.0

Iron and steel efficiency assumptions

The assumed efficiency of iron and steel production in each economy over the reference case is modeled in a similar way to the efficiency of electricity generation. As discussed in chapter 4, estimates are made of energy consumption by each process route in each economy relative to best practice in 2002. From this starting point, the energy efficiency of each process route in each economy is assumed to improve through the introduction of new capacity and the retrofitting of existing capacity over the reference case (table 25).

Forecasts of the future energy intensity of blast furnace and electric arc furnace based steel production are based on those contained in the US Energy Information Administration's National Energy Modeling System (NEMS), which underlies its Annual Energy Outlook. Specifically, it is assumed that energy consumption by the most efficient integrated steel makers is projected to fall from 19.2 gigajoules a tonne of steel produced in 2002 to 17.9 gigajoules in 2030, while that for the most energy efficient minimills is projected to fall from 4.8 gigajoules a tonne in 2002 to 3.9 gigajoules in 2030. In modeling the important contribution of retrofitting to the efficiency of steel production capacity, it is assumed in the manner of the NEMS that retrofitting can halve the efficiency gap between existing capacity and state of the art capacity (USDOE 2004d).

In addition to the differences in energy efficiency between economies discussed in chapter 4, these data indicate greater variability in the average efficiency of integrated steel making than electric arc furnace based steel

25 Average annual growth in the efficiency of steel production, by process route, reference case

	Blast furnace – basic oxygen furnace route				Electric arc furnace route			
	2002	New	2030	Growth	2002	New	2030	Growth
	GJ/t	GJ/t	GJ/t	%	%	GJ/t	GJ/t	%
Australia	23.9	21.7	21.8	0.32	6.0	4.8	4.9	0.71
Canada	23.8	21.4	21.7	0.32	5.9	4.8	4.9	0.67
Chile	28.6	23.8	24.0	0.62	7.1	5.4	5.4	0.96
China	32.6	23.8	24.6	1.01	8.1	5.5	5.7	1.29
Hong Kong, China	–	–	–	–	–	–	–	–
Indonesia	–	–	–	–	8.4	5.8	5.9	1.24
Japan	21.1	18.8	19.4	0.31	5.3	4.3	4.5	0.56
Korea	22.1	18.8	19.3	0.49	5.5	4.5	4.6	0.68
Malaysia	–	–	–	–	7.1	5.2	5.3	1.09
Mexico	23.9	22.1	22.1	0.27	6.0	4.8	4.9	0.73
New Zealand	28.6	23.8	24.5	0.56	7.1	5.4	5.5	0.93
Peru	28.6	23.8	24.2	0.59	7.1	5.4	5.5	0.94
Philippines	–	–	–	–	7.1	5.4	5.5	0.94
Russian Federation	36.6	25.5	28.0	0.94	9.1	5.9	6.2	1.36
Singapore	–	–	–	–	7.1	5.4	5.5	0.91
Chinese Taipei	22.8	19.4	20.2	0.44	5.7	4.8	4.9	0.56
Thailand	–	–	–	–	7.1	5.5	5.5	0.92
United States	23.9	21.5	21.8	0.33	6.0	4.8	4.9	0.70
Viet Nam	–	–	–	–	8.4	5.7	5.8	1.33

Note: – Occurs where economies do not use that technology. ‘New’ refers to the average energy efficiency of steel production capacity introduced between 2002 and 2030. ‘Growth’ refers to the average annual growth of energy efficiency between 2002 and 2030.

making throughout the region. This variability reflects the large differences in age and scale of integrated steel making capacity throughout APEC and the fact that electric arc furnace capacity in APEC is generally more modern than integrated steel making capacity.

Under these assumptions, the energy efficiency of steel production is projected to improve slowly over the reference case in most economies and more rapidly in economies where steel production is initially less energy efficient. The main sources of this improvement are new coke making, casting and rolling technologies, while only marginal improvement is forecast in the energy efficiency of basic oxygen furnaces or electric arc furnaces. These developments are projected to have a larger impact on energy consumption by minimills as casting and rolling account for a greater share of total energy consumption in minimills than in integrated steel mills. These assumptions imply that advanced smelt reduction and direct reduction technologies will have a minimal impact on energy consumption in the steel industry over the reference case.

Policy simulations

The reference case assumptions described above aim to capture the likely impacts of new technologies on energy consumption in the APEC region over the period to 2030, based on current expectations about the uptake and development of electricity generation and iron and steel production technologies within APEC. These expectations, in turn, are based on current trends in energy sector investment across APEC economies and current assessments of the potential market impacts of a host of new and emerging technologies. Over the period to 2030, however, it is possible that the development and uptake of new technologies in APEC economies could be influenced by events that are currently considered unlikely or are difficult to predict. These possibilities confer a degree of uncertainty on the reference case assumptions.

In this study, two major sources of uncertainty are considered. First, breakthroughs in the development of new or alternative technologies could substantially alter the efficiency of best practice technologies available to APEC economies over the reference case. Second, given the large number of drivers affecting investment in energy technologies, it is possible that the climate for new energy sector investments in APEC economies could evolve along different paths from those that are currently expected. This could have significant implications for the types of technologies introduced in APEC economies and could therefore affect the efficiency gap between the most energy efficient economies and economies where energy efficiency is lower.

Forecasting the energy efficiency of best practice technologies into the future is highly uncertain because of the difficulty in predicting whether technology developers and adopters will overcome the various hurdles associated with the development and commercialisation of new technologies and, if these hurdles are overcome, how long this process will take. These hurdles are both technical and commercial in nature. Technical hurdles involve developing the technology from an original concept to a final product, while commercial hurdles involve ensuring that the final product is cost competitive with existing technologies and can be successfully operated on a commercial scale away from the trial site. These commercial hurdles are particularly important in the electricity and steel industries, where assets are required to operate for many years to pay off their often large investment costs. As a result, the costs to businesses of investing in unsuccessful technologies are considerable.

In the reference case, this uncertainty is managed by adopting relatively conservative technology development paths consistent with the work of other forecasters, such as the International Energy Agency (for electricity technologies) and the US Energy Information Administration (for steel technologies). As discussed above, the thermal efficiencies of the most advanced gas and coal fired electricity generation technologies are assumed to reach 62 per cent and 52 per cent respectively in 2030 and, in the steel industry, energy consumption is projected to reach 17.9 gigajoules a tonne of steel for integrated steel makers and 3.9 gigajoules a tonne of steel for scrap based minimills at 2030. According to these paths, technology development mainly consists of incremental improvements to existing processes, with the exception of integrated coal gasification electricity generation, which is projected to move from the demonstration stage to the mature stage over the period to 2030.

While the best practice efficiency assumptions underlying the reference case represent significant improvements in the efficiency of electricity generation technologies, there are currently a number of research and development programs that aim to achieve much greater improvements in the efficiency of electricity generation. The US Department of Energy, through its Vision 21 program, is supporting the development of a number of energy technologies with the aim of increasing the thermal efficiency of coal and gas fired electricity generation to around 65 per cent and 75 per cent respectively by 2020 (Ruth, Worrell and Price 2001). Such efficiencies require the development of a range of new technologies for gasification of fossil fuels and separation of their byproducts, as well as new boilers and turbines capable of operating at much higher temperature and pressure than existing equipment (Ruth, Worrell and Price 2001). Many of these technologies are to be demonstrated in the FutureGen integrated coal gasification hydrogen and power generation plant (USDOE 2004e).

While the Vision 21 program is focusing mainly on gas fired and gasification based technologies, a number of other research programs, such as the European Commission's Thermie project and the US Department of Energy's USC project, are aiming to improve the efficiency of pulverised coal fired electricity generation. These programs are aiming to produce steam boilers capable of operating at steam temperatures of over 700 degrees Celsius by using materials with high heat tolerance, such as nickel based alloys (Sarver and Tanzosh 2003). These temperatures are significantly higher than the most advanced boilers currently in operation, which operate at just over 600 degrees Celsius, and are expected to deliver much higher thermal efficiencies than existing pulverised coal plants. The steam boilers developed in the Thermie project, for example, are expected to operate at steam temperatures above 720 degrees Celsius and produce electricity at between 52 and 55 per cent thermal efficiency (Bugge 2003). These and other new electricity generation technologies are discussed in appendix A.

In the steel industry, there are also a number of new technologies at varying stages of development that could significantly improve best practice energy consumption beyond reference case levels. Of these, the most significant energy savings are associated with advanced smelt reduction technologies, such as the Cyclone Converter Furnace, which, if commercialised, could produce a tonne of hot metal for around 13 gigajoules of energy (de Beer et al. 1998).

Other technologies that have the potential to further reduce energy consumption in the steel industry include strip casting, which can reduce energy consumption in the hot rolling process by up to 90 per cent, resulting in a net energy saving of around 2 gigajoules of energy for each tonne of steel rolled (Wechsler and Ferriola 2002). Analysis of these technologies indicates that they have the potential to reduce net energy consumption in integrated steel mills to around 12.5 gigajoules of energy tonne and to reduce energy consumption in scrap based minimills to around 3.5 gigajoules of energy a tonne (de Beer et al. 1998). Further discussion of potential energy saving technologies in the steel industry is presented in appendix B.

In forecasting the potential impact of new technologies on energy consumption in the region, the uncertainty surrounding the menu of best practice technologies available for use is compounded by uncertainty surrounding the extent to which those technologies will be adopted throughout the region. Among APEC economies, there are a number of factors, both industry specific and more general, that could alter the degree to which best practice technologies are introduced in the electricity and iron and steel industries. These relate to the drivers of energy technology investment discussed in chapter 5 and include expectations about future demand, the broad institutional settings governing investment in each economy, as well as specific government policies affecting investment in the energy sector.

Along with resource supply, which plays an important role in determining the relative cost of specific production processes in each economy, the latter two drivers above are important in determining the extent that best practice technologies are introduced in each economy. This is because these drivers capture the cumulative impact of a range of policies, including energy sector liberalisation, energy and environment taxes, and economy specific characteristics, including risk premiums, intellectual property and the efficiency of financial markets, on investment decisions.

Given that projections of an economy's resource supply over the reference case are probably less uncertain than projections of its institutional and policy settings, it is likely that the potential for unexpected changes to institutional and policy settings adds most uncertainty to reference case forecasts of best practice technology adoption.

In the reference case, the institutional and policy environment underpinning investment in each economy is assumed to evolve along a business as usual path. As a result, the reference case can be viewed as a future in which economies with well developed capital markets, liberal energy markets, appropriate foreign investment regimes and strong patent laws are projected to undergo little institutional change and have access to best practice technologies.

On the other hand, economies where energy market liberalisation and other institutions of trade and investment are at earlier stages of development are projected to continue developing these institutions but still find it more difficult to attract best practice technologies. In this future it is also assumed that economies retain their existing preferences for energy efficiency and, as a result, do not introduce any significant new policy measures designed to enhance energy security or reduce environmental pollution.

While these assumptions form the basis for projection, it is possible that unexpectedly rapid institutional development or unanticipated changes to the policy environment in APEC economies could alter demand for, and access to, best practice technologies in APEC over the reference case. The recent history of APEC economies, which is characterised by a significant liberalisation of energy markets and foreign investment regimes, growing environmental legislation and increasing concerns about energy security, indicates that the institutional and policy environment underpinning investment in APEC economies can change rapidly at times.

In the coming years, the institutional and policy environment in APEC could continue to change rapidly as increases in average incomes and fossil fuel consumption, particularly in less developed APEC economies, lead to increased demand for environmental legislation and increased concern for energy security.

Implementing policy simulations

In recognition of the possibility that the development of energy technologies and the institutional and policy environment in which those technologies are adopted could proceed along different paths from those forecast in the reference case, three alternative scenarios are examined in this study.

The first of these is a high technology scenario, which analyses the implications of a number of more energy efficient electricity and steel production technologies that are not assumed to feature prominently in the reference case. The second scenario is one in which some of the institutional and policy constraints on the adoption of best practice technologies throughout the region are overcome more quickly than in the reference case. The third scenario is a combination of the first two, in which technologies are both developed and adopted more rapidly than in the reference case.

These scenarios aim to estimate the sensitivity of the reference case projections to assumptions about the development and adoption of new technologies over the reference case. While the reference case projects a 'most likely' future based on current expectations, the other scenarios project possible but less likely futures in which the technologies developed and adopted in APEC are at the upper end of what is currently considered practically possible. These scenarios are discussed in more detail below and the assumed efficiencies of new electricity generation and steel production capacity in each scenario are presented in tables 27 and 28.

High technology development scenario (HT)

In this scenario it is assumed that some of the more advanced technologies currently under development but considered unlikely to be widely adopted in APEC over the reference period, such as those being pursued by the Vision 21 and Thermie programs, and some of the single vessel smelt reduction steel making technologies, are developed and commercialised more rapidly than in the reference case. This leads to the much wider adoption of advanced electricity generation and steel making technologies than in the reference case. Such a scenario could eventuate if greater resources were devoted to research and development into new technologies or as a result of unexpected breakthroughs in current research programs.

The potential significance of increased research spending is particularly important for industries such as steel, where investment in research and development is strongly influenced by the profitability of the private companies responsible for that research.

In the electricity sector, it is assumed that the thermal efficiency of new pulverised coal fired capacity is projected to reach 55 per cent in 2030. The thermal efficiency of electricity generation using simple cycle gas turbines reaches a peak of 56 per cent in 2010; the thermal efficiency of electricity generated using combined cycle gas turbines reaches 75 per cent in 2015; and the efficiency of electricity generated using integrated gasification combined cycle coal power generation plant reaches almost 62 per cent in 2020 and remains at that level thereafter (USDOE 2004f) (table 26).

These new technologies are projected to have no impact on the price of electricity, relative to the reference case. As a result, there is no overall change in the production of electricity by each fuel relative to the reference case. This assumption is consistent with the Vision 21 goal that its plants 'must be cost competitive with other energy systems with comparable environmental performance' (Ruth et al. 2001).

In the iron and steel sector, it is assumed that advanced energy efficient technologies, including single vessel smelt reduction technologies and thin strip casting, are successfully commercialised by 2030. These developments, as modeled in US Energy Information Administration National Energy Modeling System high technology scenario, are projected to reduce the specific energy consumption of integrated steel production to 12 gigajoules of energy a tonne of steel in 2030 and that of scrap based minimill production to 3.5 gigajoules of energy per tonne (USDOE 2004d). It is also assumed that the energy efficiency of steel production using direct reduced iron in electric arc furnaces is assumed to improve at the same rate as that for scrap based minimill production.

26 Assumed average thermal efficiencies of electricity generation technologies, high technology development scenario, 2030

	Reference case		High technology development scenario
	2002	2030	2030 a
	% LHV	% LHV	% LHV
Brown steaming coal			
Steam boiler	37.0	41.0	48.0
IGCC	39.0	46.0	57.8
Black steaming coal			
Steam boiler	40.0	45.0	55.0
IGCC	43.0	52.0	61.8
Oil			
Simple cycle gas turbine	34.0	40.0	56.1
Steam boiler	40.0	45.0	55.0
Gas			
Simple cycle gas turbine	34.0	40.0	56.1
Combined cycle gas turbine	55.0	62.5	75.0

a Derived from USDOE (2004f) except for steam boiler efficiencies which are derived from Sarver and Tanzosh (2003).

Because of the significant reduction in both capital and energy costs associated with these technologies, it is assumed that the price of steel in this scenario falls relative to the reference case. Associated with these price changes are changes in steel production by each process route relative to the reference case. The magnitude of these output changes are determined by the price elasticities of steel production in GTEM.

In this scenario it is also assumed that the pattern of adoption and uptake of specific technologies in each economy does not change relative to the reference case. This assumption is implemented in two ways. First, the shares of individual electricity generation and steel production technologies introduced in each economy do not change relative to the reference case. For example, the share of simple cycle and combined cycle gas turbines in new gas fired generation capacity is projected to remain constant in each economy under this scenario. Second, the gap between the best practice energy efficiency for each technology and the energy efficiency of that technology actually introduced in each economy over the period is kept at reference case levels.

Accelerated adoption scenario (AA)

In the accelerated adoption scenario it is assumed that institutional and policy developments facilitating greater demand for, and access to, best practice energy technologies in technology receiving APEC economies occur more rapidly than in the reference case. Because these developments are focused on the investment climate in the technology receiving economies, they are not assumed to affect the efficiency of best practice technologies available to APEC economies. As discussed above, this type of scenario could eventuate if present barriers to the adoption of best practice technologies in technology receiving APEC economies, such as trade barriers on plant components and fuel inputs or less developed capital markets, are overcome more rapidly than is currently expected.

These developments are assumed to halve the gap between the average energy efficiency of new capacity introduced in each economy over the reference case and the average energy efficiency of new capacity introduced in the best practice economies over the reference case. For example, in the reference case, Japan is projected to introduce the most energy efficient black steaming coal fired electricity generating capacity, with an average efficiency of 46.3 per cent, and Indonesia is projected to introduce black

27 Assumed average thermal efficiency of new electricity generation capacity under each policy scenario, 2002–30

	Brown steaming coal			Black steaming coal		
	AA	HT	AAHT	AA	HT	AAHT
	%	%	%	%	%	%
Australia	37.3	44.6	45.9	45.2	50.4	52.0
Canada	38.3	44.6	45.9	45.1	50.5	52.0
Chile	–	–	–	43.2	45.6	49.6
China	–	–	–	41.7	42.0	47.8
Hong Kong, China	–	–	–	45.2	50.2	51.9
Indonesia	–	–	–	42.5	43.9	48.8
Japan	–	–	–	46.3	53.6	53.6
Korea	–	–	–	45.9	52.4	53.0
Malaysia	38.3	44.6	45.9	42.5	43.9	48.8
Mexico	39.2	47.0	47.1	–	–	–
New Zealand	–	–	–	45.1	50.4	52.0
Peru	–	–	–	43.2	45.6	49.6
Philippines	–	–	–	42.5	43.9	48.8
Russian Federation	37.8	43.4	45.3	42.7	44.4	49.0
Singapore	–	–	–	-	-	-
Chinese Taipei	–	–	–	45.2	50.2	51.9
Thailand	28.0	28.0	28.0	42.5	43.9	48.8
United States	38.3	44.6	45.9	45.1	50.5	52.0
Viet Nam	–	–	–	42.5	43.9	48.8
	Oil			Natural gas		
Australia	39.7	48.3	49.7	50.2	61.3	62.6
Canada	39.7	48.3	49.7	49.9	61.3	62.6
Chile	29.0	29.0	29.0	49.3	59.2	61.6
China	20.0	20.0	20.0	49.1	59.3	61.7
Hong Kong, China	39.7	48.3	49.7	51.6	64.0	64.0
Indonesia	38.5	50.3	50.7	47.2	56.6	60.3
Japan	38.9	38.9	38.9	51.6	64.0	64.0
Korea	35.3	35.3	35.3	51.6	64.0	64.0
Malaysia	36.0	36.0	36.0	47.5	57.0	60.5
Mexico	28.0	28.0	28.0	49.3	59.2	61.6
New Zealand	39.7	48.3	49.7	51.4	63.7	63.8
Peru	39.3	48.1	49.6	49.3	59.2	61.6
Philippines	29.5	29.5	29.5	49.8	59.8	61.9
Russian Federation	11.1	11.1	11.1	44.2	52.8	58.4
Singapore	31.5	31.5	31.5	50.5	60.7	62.4
Chinese Taipei	30.5	30.5	30.5	50.3	61.9	63.0
Thailand	34.0	34.0	34.0	49.8	59.8	61.9
United States	28.0	28.0	28.0	49.9	61.3	62.6
Viet Nam	31.2	31.2	31.2	47.7	57.2	60.6

Note: – Occurs where economies do not use that technology. AA = Accelerated adoption scenario, HT = High technology scenario, AAHT = Accelerated adoption / high technology scenario.

steaming coal fired capacity with an average efficiency of 38.8 per cent. In the accelerated adoption scenario, however, Indonesia is projected to introduce black steaming coal fired capacity with an average efficiency of 42.5 per cent (table 27).

As in the high technology development scenario, the adoption of more efficient technologies in the accelerated adoption scenario is assumed to affect prices and output in the steel industry but not in the electricity industry.

High technology – accelerated adoption scenario (AAHT)

In this scenario, it is assumed that electricity generation and steel making technologies develop as in the high technology scenario and that economies

28 Assumed average energy efficiency of new steel production capacity under each policy scenario, 2002–30

	Blast furnace – basic oxygen furnace route			Electric arc furnace route		
	AA	**HT**	**AAHT**	**AA**	**HT**	**AAHT**
	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t	GJ/t
Australia	20.1	18.2	16.9	4.5	3.8	3.6
Canada	20.0	17.8	16.7	4.5	3.8	3.6
Chile	21.1	20.3	17.9	4.9	4.4	3.9
China	21.1	20.3	17.9	4.9	4.5	3.9
Hong Kong, China	–	–	–	–	–	–
Indonesia	–	–	–	5.1	4.7	4.0
Japan	18.6	15.6	15.6	4.3	3.4	3.4
Korea	18.6	15.6	15.6	4.4	3.5	3.4
Malaysia	–	–	–	4.7	4.1	3.7
Mexico	20.3	18.4	17.0	4.6	3.8	3.6
New Zealand	21.1	20.3	17.9	4.9	4.4	3.9
Peru	21.1	20.3	17.9	4.9	4.4	3.9
Philippines	–	–	–	4.9	4.4	3.9
Russian Federation	22.0	21.5	18.5	5.1	4.8	4.1
Singapore	–	–	–	4.9	4.4	3.9
Chinese Taipei	19.0	16.3	15.9	4.6	3.7	3.5
Thailand	–	–	–	4.9	4.4	3.9
United States	20.0	18.0	16.8	4.5	3.8	3.6
Viet Nam	–	–	–	5.0	4.6	4.0

Note: – Occurs where economies do not use that technology. AA = Accelerated adoption scenario, HT = High technology scenario, AAHT = Accelerated adoption / high technology scenario.

adopt this technology to the same degree as in the accelerated adoption scenario. This scenario represents a practical upper limit on the impact of new technologies on energy consumption and greenhouse gas emissions in the electricity and iron and steel industries in APEC over the period to 2030. In this scenario, the gap between the average energy efficiency of new capacity introduced in each economy and the average energy efficiency of new capacity introduced in the best practice economies in the high technology development scenario over the period to 2030 is halved (table 28).

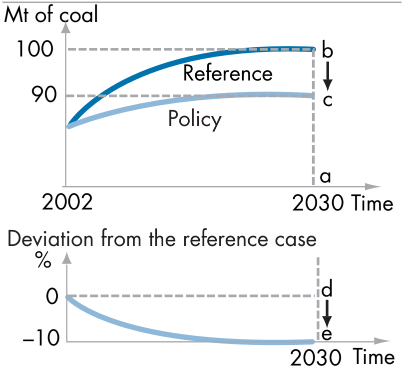
Interpreting results

As a dynamic general equilibrium model, GTEM is able to capture the change in magnitude over time of a range of economic variables, including sectoral and regional output, trade and investment flows, regional income and expenditure levels, and prices of producer and consumer goods. The estimated impacts of policy and other changes can be expressed as absolute values or as percentage changes in the values of these variables over the projection period.

For example, in a high technology development scenario, the impact of introducing more efficient coal fired electricity generation capacity on coal consumption in the electricity sector can be identified by comparing the growth in coal consumption in the electricity sector in this scenario with its growth in the reference case, as illustrated in figure 10.

In this figure, coal consumption in the electricity sector in a particular economy is projected to reach 100 million tonnes of coal in 2030 in the reference case. Following the development of more efficient technologies, coal consumption in the electricity industry in this economy is projected to reach 90 million tonnes at 2030. This corresponds to a 10 per cent decrease in coal consumption in the electricity sector at 2030 compared with the reference case projection.

10 **Interpreting results from GTEM simulations**



Reference case projections

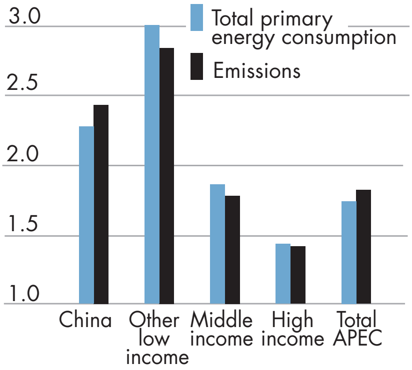
Total primary energy consumption in the reference case is projected to grow at 2.1 per cent a year between 2002 and 2030. This growth implies that total energy consumption in APEC will expand by around 77 per cent over the period, increasing from 5513 million tonnes of oil equivalent (Mtoe) in 2002 to 9750 Mtoe in 2030 (figure 11). This growth in energy consumption is matched by similar growth in greenhouse gas emissions in most APEC economies.

Energy consumption and greenhouse gas emissions are projected to expand most strongly in China and other low income APEC economies as a result of relatively rapid economic growth and increased demand for personal services. Because of its rapid growth and large initial energy consumption, China alone is projected to account for a third of the energy consumption growth and over 40 per cent of the growth in greenhouse gas emissions in APEC between 2002 and 2030. This growth is projected to result in China accounting for a larger share of APEC energy consumption and greenhouse gas emissions in 2030 than in 2002.

In the middle income APEC economies, economic growth of over 4 per cent a year is projected to result in energy consumption and greenhouse gas emissions almost doubling between 2002 and 2030, which is projected to lead to a slight reduction in the share of these economies in total APEC energy use and greenhouse gas emissions.

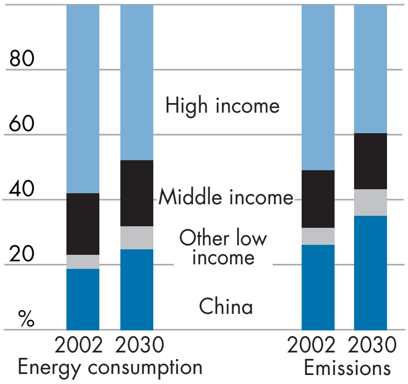
11 **Change in APEC energy consumption, 2002–30**

Reference case, 2002 = 1.0



In the high income APEC economies, economic growth below 3 per cent a year over the period is projected to lead to slower growth in energy consumption and greenhouse gas emissions than elsewhere in the region (figure 12). As a result, the share of high income APEC economies in total APEC energy consumption is projected to fall from almost 60 per cent in 2002 to around 47 per cent in 2030. Similarly, the share of high income economies in total APEC greenhouse gas emissions is projected to fall from about 50 per cent in 2002 to about 40 per cent in 2030, with most of the difference being taken up by China.

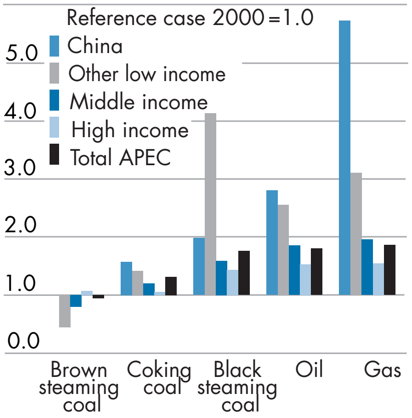
12 **APEC shares, by income group** Reference case



Fossil fuels are projected to retain their dominant share of APEC energy consumption, accounting for about 90 per cent of the growth in total APEC energy consumption over the projection period. Black steaming coal, oil and natural gas are projected to account for the vast majority of this growth, while much slower growth is projected in coking coal consumption. Brown coal consumption is projected to fall slightly over the period (figure 13).

The strong growth in black steaming coal and natural gas consumption, particularly in China and other low income APEC economies, occurs largely because of increased demand for these fuels for electricity generation. Similarly, the reduction in APEC consumption of brown coal reflects a substitution away from this more polluting fuel in electricity generation throughout the region. Coking coal consumption growth occurs mostly in China as China is projected to account for most of the new blast furnace based steel production in APEC over the period.

13 **Change in APEC coal, oil and gas consumption, 2002–30**



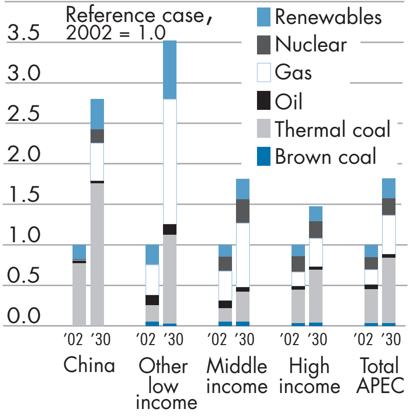
The growth in oil consumption throughout APEC is driven mainly by increased demand from the transport sector, where there are limited substitution possibilities. In the low and middle income APEC economies, transport sector growth is influenced mainly by increasing economic growth and private vehicle ownership. In the high income APEC economies, transport sector growth is a function of both economic growth and the growing role of service industries in economic activity.

The changes in the composition of fuel consumption in APEC over the reference case are driven to a large extent by growth in electricity generation across the region. As discussed in chapter 3, the growth in electricity output and its implications for fossil fuel consumption are largely influenced by the stage of development of economies throughout the region.

Over the reference case, China and other low income APEC economies are projected to account for more than half the growth in electricity generation in the region, despite generating only 20 per cent of the region's electricity in 2002 (figure 14). In China, this increased output is characterised by increasing shares of natural gas and renewable energy sources in the electricity fuel mix. In other low income economies, where most new power generation capacity is expected to be for base load electricity demand, the role of black steaming coal in electricity generation is projected to increase, reflecting the continued competitiveness of black steaming coal in providing base load power.

The cost competitiveness of natural gas turbines for peaking capacity is one reason for the increasing share of natural gas in the electricity fuel mix in high income APEC economies, where peaking capacity is projected to account for a larger share of new power generation capacity than in other economies.

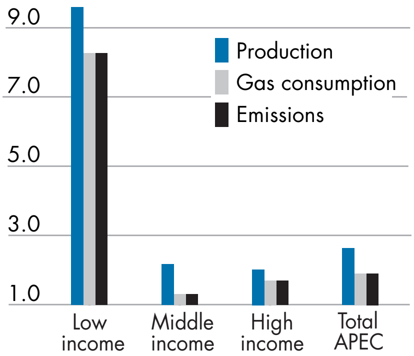
14 **Growth in APEC electricity generation, by fuel**



The growth in energy consumption and greenhouse gas emissions in APEC over the period is moderated to a degree by continued improvements in energy efficiency, particularly in less energy efficient economies where opportunities for rapid technological catch-up exist. These efficiency improvements are based on the assumptions presented in table 21 and can be seen clearly by comparing the growth in output and energy consumption by industry in each economy. For example, in 2030, APEC economies are projected to produce 2.6 times as much natural gas fired electricity as in 2002, using only 1.9 times as much natural gas and generating only 1.9 times as many greenhouse gas emissions (figure 15).

15 Change in APEC natural gas fired electricity, 2002–30

Reference case, 2002 = 1.0



This efficiency improvement effectively reduces the energy consumption and greenhouse gas emissions associated with natural gas fired electricity generation at 2030 by 25 per cent compared with the situation without the efficiency improvements. These efficiency improvements are particularly large in the middle income APEC economies, mainly because of rapid output growth and technological catch-up in the Russian Federation but also because of the high efficiency of new power generation capacity in Korea and, to a lesser extent, Mexico.

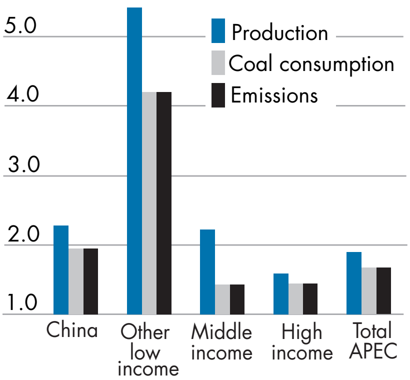
In the low income group, huge growth in the output of gas fired electricity is projected to be accompanied by smaller energy efficiency improvements than those attained in middle income economies. The smaller efficiency improvement reflects the high initial efficiency of gas fired power generation in a number of low income APEC economies, such as Indonesia, the Philippines, Thailand and Viet Nam, and occurs despite the large efficiency improvements in China.

In high income APEC economies, efficiency improvements are also projected to occur most rapidly in economies where the initial efficiency of gas fired power generation capacity is low, such as Australia and the United States. With the exception of Korea, higher income APEC economies are projected to introduce slightly more efficient natural gas fired power generation capacity over the period than the other APEC economies as demand for energy efficiency in these economies is assumed to be higher than in the rest of APEC.

Black steaming coal fired electricity generation in APEC is projected to grow at a slower rate than natural gas fired electricity over the reference case. This

16 Change in APEC black steaming coal fired electricity, 2002–30

Reference case, 2002 = 1.0

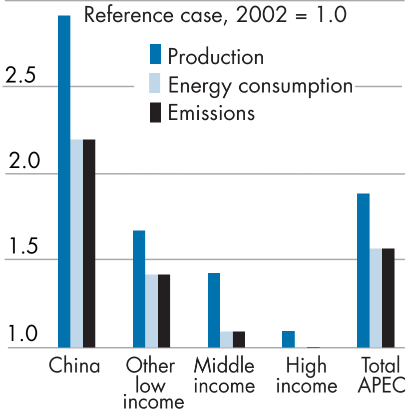


slower output growth, combined with less widespread adoption of advanced electricity generation technologies, is projected to result in slower improvement in the energy efficiency of black steaming coal fired power generation over the reference case than that projected for natural gas (figure 16). As a result, the gap between the growth in black steaming coal fired electricity generation and the energy use and greenhouse gas emissions resulting from that output, is projected to be smaller than for natural gas fired power generation.

Similarly, efficiency improvements in the production of iron and steel are projected to reduce energy consumption and greenhouse gas emissions in both blast furnace based and electric arc furnace based steel production by 17 per cent and 19 per cent respectively relative to what they would otherwise have been. China is projected to be the main source of this improvement, introducing 85 per cent of new blast furnace based steel production capacity in APEC over the period and improving the energy efficiency of its blast furnace based production by 1 per cent a year (figure 17). Most of the rest of this improvement is projected to occur in middle income APEC economies, particularly the Russian Federation, which is projected to benefit significantly from the introduction of more efficient new capacity, and in Korea, which is expected to remain among the world's most efficient steel producers over the reference case.

17 Change in APEC blast furnace based steel, 2002–30

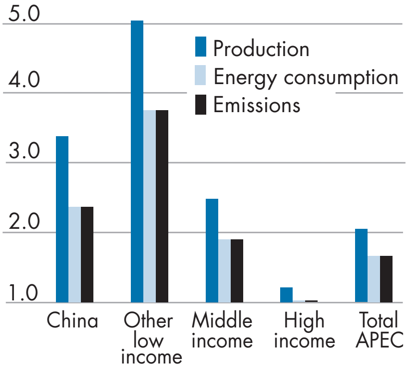
Reference case, 2002 = 1.0



In the higher income APEC economies, slow growth in the output of blast furnace based steel is projected to be almost matched by improvements in the energy efficiency of this process route. As a result, the energy consumption and greenhouse gas emissions resulting from blast furnace based steel production are projected to remain relatively constant over the projection period.

18 Change in APEC electric arc furnace based steel, 2002–30

Reference case, 2002 = 1.0



Although accounting for much less new steel production capacity in absolute terms, the output of electric arc furnace based steel is projected to grow more rapidly than blast furnace based steel over the reference case, particularly outside China, increasing from almost 31 per cent of APEC steel production in 2002 to around 33 per cent in 2030 (figure 18). As a result of this increased output growth and the impact of new casting and rolling techniques on the energy efficiency of this process route, the energy efficiency of electric arc based steel making in each APEC economy is projected to improve more rapidly over the reference case than that of blast furnace based steel production.

Although the share of steel produced in electric arc furnaces in China is expected to remain relatively constant over the period, China is still projected to account for more new electric arc based steel production than any other APEC economy and the energy efficiency of its electric arc sector is projected to improve considerably over the period.

The most rapid output growth is projected to occur in other lower income APEC economies, including Indonesia, Thailand and Viet Nam, where energy efficiency improvements resulting from the introduction of new capacity are projected to reduce energy consumption and greenhouse gas emissions from electric arc furnace based steel production by more than 20 per cent of what it would otherwise have been. A similar efficiency improvement is projected in middle income APEC economies, where most of the new electric arc furnace capacity consists of highly efficient capacity introduced in Korea and Mexico. This new capacity is complemented by strong efficiency improvements resulting from rapid output growth in Chile and Malaysia and continued modernisation in the Russian Federation.

In the higher income APEC economies, most of the new electric arc furnace based steel production occurs in the United States and, to a lesser extent, Chinese Taipei. Electric arc based steel production in Japan is projected to fall slightly over the reference case as Japan continues to focus on producing high value flat products using its highly efficient blast furnaces. This is projected to slow the efficiency improvement in Japan's electric arc furnaces. Overall, slower growth in steel production in the higher income economies, combined with relatively energy efficient initial capacity, results in smaller efficiency gains than elsewhere in APEC.

7

quantifying the impacts of new technologies in APEC

- The accelerated development and adoption of new electricity generation technologies in APEC could reduce energy consumption in the electricity industry by around 460 million tonnes of oil equivalent, relative to the reference case at 2030.

- In the steel industry, the accelerated development and adoption of new iron and steel production technologies could reduce energy consumption in APEC by 89 million tonnes of oil equivalent at 2030, relative to the reference case.

- The more rapid development of energy efficient technologies is the major contributor to this result. In the high technology development scenario, fossil fuel consumption in electricity generation is projected to fall by 344 million tonnes of oil equivalent at 2030, relative to the reference case.

- However, the accelerated adoption of more energy efficient electricity generation and steel production technologies is also a potentially important avenue for efficiency improvement, particularly in economies away from the technological frontier.

- In the accelerated adoption scenario, the energy efficiency of coal fired electricity generation in China is projected to improve by 8.5 per cent relative to the reference case at 2030, while the energy efficiency of gas fired electricity generation in the Russian Federation is projected to improve by more than 12 per cent relative to the reference case at 2030.

In the reference case described in the previous chapter, changes in the energy efficiency of electricity generation and steel production throughout APEC between 2002 and 2030 are shown to have important impacts on the growth of energy consumption in these industries. The efficiency changes in the reference case are driven by the introduction of new electricity generation and steel production capacity over the period. In each economy, the change in energy efficiency of electricity generation by each fuel type and iron and steel production by each process route is a function of the difference in energy efficiency of existing and new capacity and the amount of new capacity introduced over the period. Other things being equal, the larger the difference in the energy efficiency of existing and new capacity in an economy, the larger the change in energy efficiency over the period, and the faster the introduction of new capacity in an economy over the period, the larger the change in energy efficiency.

As a result, the reference case projections of energy consumption in these industries are sensitive to the assumptions made about the energy efficiency of new capacity in each economy. These are in turn based on assumptions about the energy efficiency of various technologies available to electricity and steel producers in each economy and the extent that those producers will adopt them. As discussed in the previous chapter, uncertainties relating to both the development of electricity generation and steel production technologies over the period, and the extent of their adoption throughout APEC, have led to the analysis of three alternative scenarios in this study. These scenarios are:

- A high technology development scenario (HT) — in which a number of advanced electricity generation and steel production technologies are developed that lead to significant improvements in the maximum energy efficiency of new capacity available to electricity generators and steel producers in APEC over the period, relative to the reference case.
- An accelerated adoption scenario (AA) — in which the development of conditions facilitating greater demand for, and access to, the most energy efficient technologies in economies away from the technological frontier leads to the more rapid diffusion of energy efficient technologies throughout APEC over the period.
- A high technology development scenario with accelerated adoption (AAHT) — in which technology develops as in the high technology development scenario and is diffused throughout APEC as in the accelerated adoption scenario.

In addition to the specific energy efficiency assumptions for each technology in each economy in these scenarios, a key assumption is that advanced electricity generation technologies are cost competitive with existing technologies and, as such, do not affect the price of electricity generation in each economy. This assumption is consistent with the electricity technology goals of the Vision 21 research program on which some of the thermal efficiency assumptions used in the high technology development scenario are based. As a result, although the energy efficiency of electricity generation by each fuel type in each economy changes considerably in these scenarios relative to the reference case, the total amount of electricity generated by each fuel type in each economy does not change.

A second key assumption is that more energy efficient steel making technologies are introduced because they are less costly than existing technologies. This assumption is consistent with the focus of technology development in the steel industry, which is on the development of techniques capable of producing steel at lower cost using inputs of lower value.

This chapter presents the key results of these scenarios for the electricity and iron and steel industries throughout APEC. To simplify the discussion and better illuminate the trends evident across the region, the results are presented for the economy groups discussed elsewhere in this study: China; other low income economies; middle income economies; high income economies; and APEC as a whole, with references to individual economies where necessary. More detailed results for each economy are presented in appendix C.

High technology development scenario

In this scenario, the more energy efficient electricity generation and steel production technologies introduced throughout APEC are projected to benefit the region in the form of lower fossil fuel consumption and reduced steel prices, relative to the reference case. These savings are projected to lead to increased economic activity in the region, increasing the real GDP of APEC economies as a whole by 0.17 per cent relative to the reference case at 2030.

In the electricity sector the efficiency improvements modeled in this scenario are projected to reduce fossil fuel consumption in APEC by around 344 million tonnes of oil equivalent at 2030 (table 29). This energy saving is equivalent to more than 30 per cent of the growth in fossil fuel consumption in the electricity sector in APEC. These reductions are projected to be largest for natural gas and black steaming coal. This is in part attributable to the large absolute improvements in the thermal efficiency of natural gas

29 Fossil fuel consumption in electricity generation in APEC under the high technology development scenario, 2030

	Reference case		High technology development	
	2002 a	**2030**	**2030**	**Savings at 2030**
	Mtoe	Mtoe	Mtoe	Mtoe
Brown steaming coal	91.8	87.2	79.4	–7.8
Black steaming coal	1 065.3	1 774.9	1 615.9	–159.0
Oil	134.6	98.1	95.4	–2.7
Natural gas	480.0	917.1	742.5	–174.6
Total	1 771.7	2 877.4	2 533.3	–344.1

a IEA (2004a).

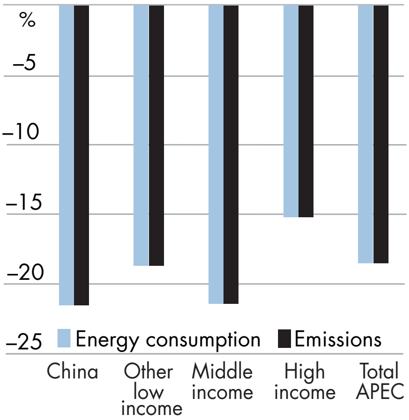
fired electricity generation in the scenario and in part these technologies are projected to supply the majority of new electricity generation capacity in APEC over the reference case.

These efficiency improvements are projected to reduce the energy consumption and greenhouse gas emissions from natural gas fired electricity generation in APEC by 174 million tonnes of oil equivalent (or around 19 per cent) relative to the reference case at 2030 (figure 19).

With the exception of the Russian Federation, these efficiency improvements are projected to occur most strongly in economies where the growth of natural gas fired electricity generation is greatest over the reference case. For example, in China and other low income economies such as Peru and Viet Nam, where natural gas fired electricity generation is projected to grow rapidly, natural gas consumption in electricity generation is projected to fall by more than 22 per cent at 2030 in this scenario relative to the reference case.

19 Change in APEC natural gas fired electricity generation at 2030

High technology development scenario relative to reference case



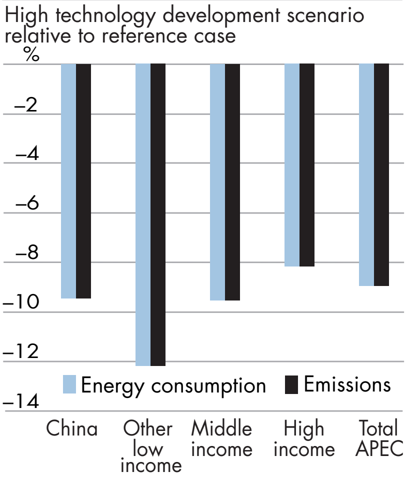
On the other hand, in economies with much slower growth in natural gas fired electricity generation, including Hong Kong, China; Japan; and New Zealand, natural gas consumption in electricity generation at 2030 is projected to fall by 13 per cent or less relative to the reference case.

In the Russian Federation, natural gas consumption in electricity generation at 2030 is projected to fall by around 24 per cent relative to the reference case despite the slow growth in gas fired electricity generation over the period. This occurs as a result of the large improvement in the thermal efficiency of new gas fired capacity in the Russian Federation in this scenario, which is a function of the relatively large improvement in simple cycle gas turbine efficiency in this scenario, and Russia's intensive use of this technology.

These new technologies are projected to have less impact on the efficiency of black steaming coal fired electricity generation in APEC than on gas fired generation, with the consumption of black steaming coal in electricity generation falling by 9 per cent relative to the reference case at 2030 (figure 20). However, because of the large consumption of black steaming coal in electricity generation in APEC, this improvement is projected to have almost as large an effect on total energy consumption in electricity generation as those for natural gas fired electricity capacity.

As was the case for natural gas fired capacity, the largest efficiency improvements are projected to occur in economies, such as Indonesia, Malaysia, Peru, Thailand and Viet Nam, with more rapid growth in black steaming coal fired electricity generation. This is projected to occur despite the fact that the technology improvements have a larger impact on the efficiency of integrated gasification combined cycle coal plants, which are more widely introduced in higher income economies where growth in coal fired electricity generation is generally slower, such as Australia, Canada, Japan, New Zealand and the United States.

20 Change in APEC black steaming coal fired electricity generation at 2030



In the steel industry, the accelerated development of advanced energy efficient technologies modeled in this scenario is projected to reduce the growth in energy consumption by the steel industry from approximately 1.6 per cent a year over the reference case to around 1 per cent a year in this scenario (table 30). These developments are also projected to reduce the production costs of each steel making process in APEC, which leads to increased steel demand throughout the region and also changes the competitiveness of steel producers within APEC.

There are two main reasons for the change in competitiveness. The first is that, as in the reference case, these advanced technologies are adopted more widely in APEC economies with more energy efficient steel industries, such as Japan and Korea. The second is that the improvements have a greater impact on the energy efficiency of electric arc furnace capacity than that of integrated steel making capacity. As a result, the output of steel is projected to increase most in the more energy efficient high and middle income APEC economies where electric arc furnaces account for a large share of total steel production but to fall slightly in low income economies where steel production is less energy efficient and where integrated steel making technologies dominate.

In the electric arc furnace sector, these developments are projected to result in an APEC-wide energy efficiency improvement of about 20 per cent relative to the reference case at 2030 (figure 21). As discussed earlier, this improvement is largest in the middle and high income APEC

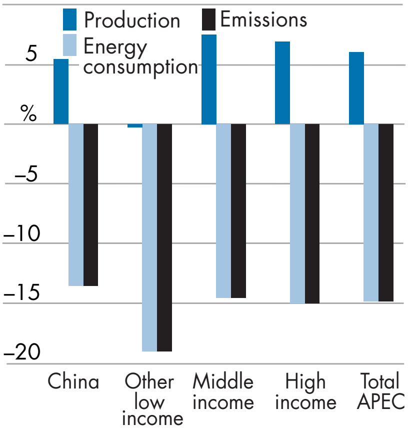
30 **Average annual growth in output and energy consumption in the steel industry in APEC under the high technology development scenario, 2002–30**

	Reference case		High technology development	
	Output	Energy consumption	Output	Energy consumption
	%	%	%	%
China	4.0	2.9	4.0	2.3
Other low income	5.9	4.6	5.9	3.8
Middle income	2.1	0.6	2.3	0.1
High income	0.5	0.0	0.5	–0.6
APEC	2.4	1.6	2.4	1.0

economies, where the production of steel in electric arc furnaces is projected to increase by more than 7 per cent relative to the reference case at 2030 and energy consumption and greenhouse gas emissions are projected to fall by around 15 per cent relative to the reference case at 2030. The production of steel using electric arc furnaces is also projected to become significantly more energy efficient in China and other lower income economies under this scenario.

21 Change in APEC electric arc furnace based steel mills at 2030

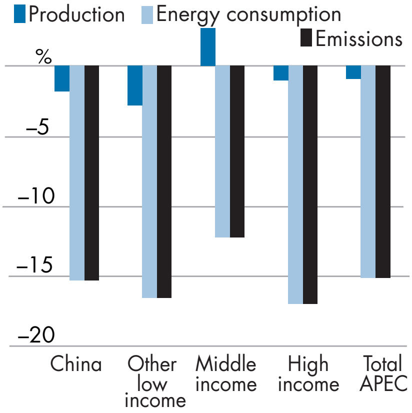
High technology development scenario relative to reference case



In the integrated steel making sector, a smaller APEC-wide energy efficiency improvement of around 14 per cent relative to the reference case at 2030 is evident (figure 22). As is the case in electric arc furnace steel production, these energy efficiency improvements and greenhouse gas emission reductions are larger in the high and middle income APEC economies. Whereas the output of electric arc furnace based steel increases in most APEC economies relative to the reference case, production of steel through integrated routes in this scenario is projected to fall relative to the reference case in all economies except Canada, Korea and the Russian Federation.

22 Change in APEC integrated steel making processes at 2030

High technology development scenario relative to reference case



In these economies, the productivity improvements resulting from the new technologies improve the competitiveness of both integrated and electric arc furnace based steel producers relative to producers in other economies, resulting in demand for steel produced by both electric arc furnace and integrated steel production routes increasing relative to the reference case.

As a result of these changes, the share of total steel produced by integrated steel production routes is projected to fall from 67.4 per cent in 2030 under the reference case to 65.9 per cent in 2030 under this scenario. Similarly, China's share of steel production in APEC at 2030 is projected to fall from 50.4 per cent under the reference case to 49.5 per cent in this scenario. Despite this, China is still projected to introduce around 67 per cent of all new steel production capacity in APEC in this scenario.

Accelerated adoption scenario

In this scenario, the gap between the energy efficiency of new capacity introduced in each economy and that of new capacity introduced in the best practise economies is halved. This more rapid diffusion of more energy efficient technologies in economies away from the technological frontier is projected to reduce energy consumption and steel prices in APEC. At 2030, these improvements are projected to increase real GDP in APEC as a whole by 0.05 per cent relative to the reference case.

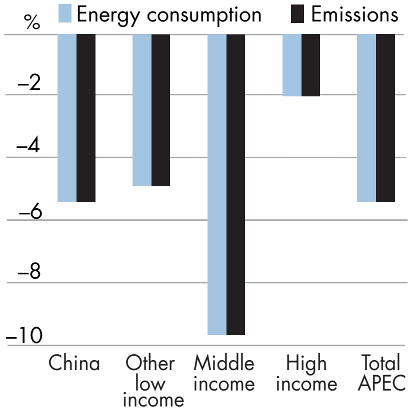
In the electricity sector, the more widespread diffusion throughout APEC of advanced electricity generation technologies is also projected to reduce the amount of fossil fuels consumed in electricity generation by 137 million tonnes of oil equivalent at 2030, relative to the reference case. As in the high technology scenario, the largest differences in energy consumption are projected to occur in natural gas fired electricity generation, because natural gas technologies are introduced more rapidly than other technologies (table 31).

Although the APEC wide reductions in fossil fuel consumption by the electricity sector relative to the reference case are not as large as in the high technology scenario, these reductions are potentially more achievable in economies that do not play a direct role in the development of new electricity generation technologies.

As expected, the largest efficiency gains are projected to occur in economies that introduced the least thermally efficient electricity generation capacity over the reference case. The largest reductions in natural gas consumption and its associated greenhouse gas emissions are projected to occur in the Russian Federation, where the average efficiency of new natural gas fired capacity introduced over the period is projected to increase from 36.7 per cent in the reference case to 44.2 per cent (figure 23). The increased efficiency is projected to reduce the natural gas consumption and greenhouse gas emissions of gas fired electricity generation in the Russian Federation by 12 per cent relative to the reference case at 2030.

23 Change in APEC gas fired electricity generation at 2030

Accelerated adoption scenario relative to reference case



After the Russian Federation, large efficiency gains of more than 7 per cent relative to the reference case at 2030 are projected in the low income economies of Indonesia and Viet Nam, while efficiency improvements of between 5 and 7 per cent relative to the reference case at 2030 are forecast in China, Malaysia and Peru. Lower efficiency improvements of between 2 and 5 per cent relative to the reference case at 2030 are projected in most of the remaining economies, except for those economies that are close to best practice over the reference case, including Hong Kong, China; Japan; Korea; and New Zealand.

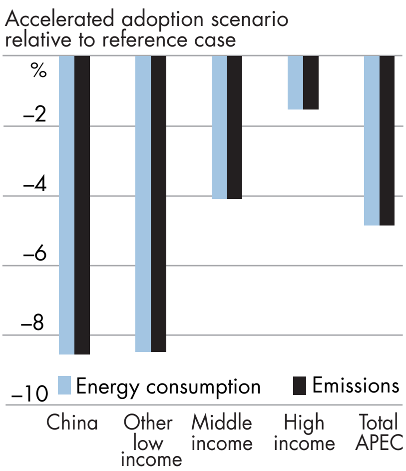
In the case of black steaming coal fired electricity generation, the largest efficiency improvements are projected to occur in China and other low income economies. In China the average efficiency of new black steaming coal capacity is projected to increase from 37.1 per cent in the reference case to 41.7 per cent in this scenario. Other large efficiency improvements

31 Fossil fuel consumption in electricity generation in APEC under the accelerated adoption scenario, 2030

	Reference case		Accelerated adoption	
	2002 a Mtoe	**2030** Mtoe	**2030** Mtoe	**Savings at 2030** Mtoe
Brown steaming coal	91.8	87.2	85.5	–1.7
Black steaming coal	1 065.3	1 774.9	1 688.9	–86.0
Oil	134.6	98.1	97.8	–0.3
Natural gas	480.0	917.1	868.0	–49.1
Total	1 771.7	2 877.4	2 740.2	–137.2

a IEA (2004a).

24 Change in APEC black steaming coal fired electricity generation at 2030



of between 8 and 9 per cent relative to the reference case at 2030 are projected to occur in Indonesia, Malaysia, Thailand and Viet Nam, where efficiency improvements are complemented by rapid growth in the output of black steaming coal fired electricity (figure 24).

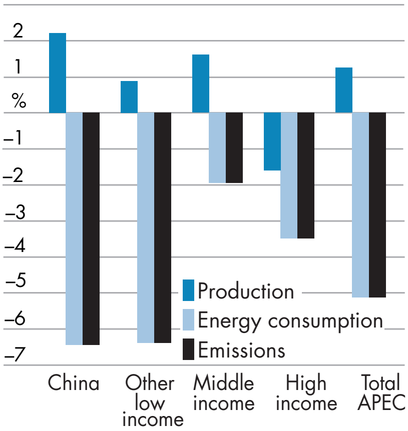
As is the case in natural gas fired electricity generation in this scenario, smaller efficiency improvements are projected in other middle income economies where black steaming coal is used in electricity generation. In high income APEC economies where the thermal efficiency of black steaming coal fired generation capacity is assumed to be higher over the reference case, low efficiency improvements of less than 2 per cent relative to the reference case at 2030 are projected under this scenario.

Reflecting the importance of technology choice in the steel industry, the increased uptake of more efficient technologies in economies away from the technology frontier is projected to lead to more rapid growth in steel production but slower growth in energy consumption than that which occurred in the reference case (table 32). These improvements are projected to be concentrated in low and middle income economies that would otherwise introduce less energy efficient steel production capacity. Also, because more of the new integrated steel making capacity over the period is introduced in economies away from the technological frontier, this accelerated adoption is projected to have the most impact on energy efficiency in the integrated steel making sector.

Because these efficiency improvements affect the price of steel produced by each process route, this accelerated adoption is also projected to result in a slight increase in the share of integrated steel production in total APEC steel production. As a result of these improvements, the share of China and other low income economies in APEC steel production at 2030 is projected to increase from 53.4 per cent in the reference case to 54.2 per cent in this scenario, mainly at the expense of steel producers in the high income economies.

25 Change in APEC integrated steel making processes at 2030

Accelerated adoption scenario relative to reference case



The more widespread adoption of energy efficient steel production technologies in APEC under this scenario is projected to improve the energy efficiency of integrated steel production in APEC by around 6 per cent relative to the reference case at 2030. The energy efficiency of the least energy efficient integrated steel producers, Chile, China, Peru and the Russian Federation, is projected to improve by between 7 and 9 per cent, relative to the reference case at 2030 (figure 25). This efficiency improvement is associated with increased integrated steel production of 2.2 per cent and 7.6 per cent in China and the Russian Federation respectively, relative to the reference case at 2030.

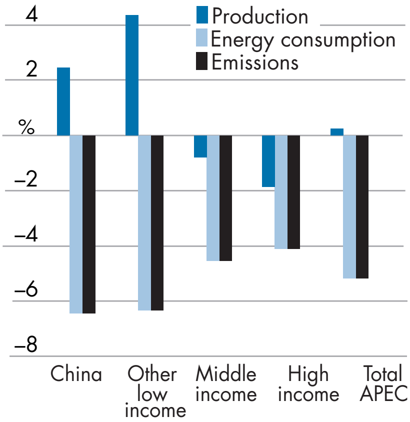
More moderate energy efficiency gains and associated greenhouse gas emission reductions of around 4 per cent at 2030 relative to the reference case are projected in economies with average energy efficiency in integrated

32 Average annual growth in output and energy consumption in the steel industry in APEC under the accelerated adoption scenario, 2002–30

	Reference case		**Accelerated adoption**	
	Output	**Energy consumption**	**Output**	**Energy consumption**
	%	%	%	%
China	4.0	2.9	4.1	2.6
Other low income	5.9	4.6	6.0	4.3
Middle income	2.1	0.6	2.1	0.5
High income	0.5	0.0	0.4	–0.1
APEC	2.4	1.6	2.4	1.5

26 **Change in APEC electric arc furnace based steel mills at 2030**

Accelerated adoption scenario relative to reference case



steel making, including Australia and the United States. In the most energy efficient integrated steel makers, such as Korea and Japan, minimal energy efficiency improvement is projected under this scenario and production of steel using the integrated route is projected to fall slightly relative to the reference case at 2030.

The accelerated adoption of more energy efficient steel making technologies is projected to improve the energy efficiency of steel production using electric arc furnaces throughout APEC by around 5 per cent relative to the reference case at 2030 (figure 26). In economies where the energy efficiency of electric arc furnaces introduced over the reference case is relatively low, such as Chile, China, Indonesia, Peru, Philippines, the Russian Federation, Thailand and Viet Nam, these efficiency improvements are projected to be between 8 and 12 per cent, relative to the reference case at 2030. Moderate efficiency improvements of 4 per cent and 7 per cent relative to the reference case at 2030 are projected in Malaysia and Mexico respectively, while in most of the high income economies, these efficiency improvements are projected to be less than 3 per cent relative to the reference case at 2030.

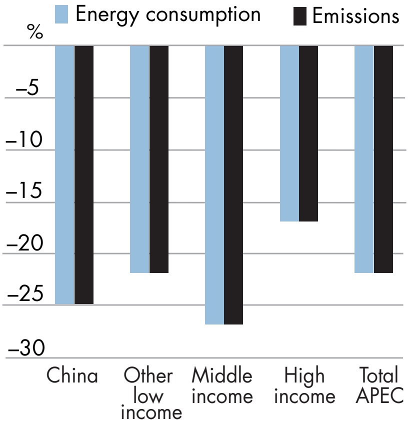
High technology development scenario with accelerated adoption

In this scenario the combination of more rapid technology development and adoption, as modeled individually in the previous two scenarios, is projected to result in larger improvements in the efficiency of fuel use in the electricity and steel industries than observed in the previous scenarios. These improvements are projected to result in increases in economic activity throughout the region, with real GDP in APEC at 2030 increasing by 0.22 per cent relative to the reference case.

In the electricity sector, the successful development and more widespread adoption of advanced electricity generation technologies is projected to reduce fossil fuel consumption in electricity generation in APEC by 460 million tonnes of oil equivalent at 2030 (table 33). This energy saving is projected to reduce the growth in fossil fuel consumption in the electricity sector in APEC by more than 40 per cent relative to the reference case. This equates to more than 10 per cent of the total growth in energy consumption in APEC over the reference case.

27 Change in APEC natural gas electricity generation at 2030

High technology development scenario with accelerated adoption relative to reference case



As in the high technology development scenario, the largest efficiency improvements are projected to occur in natural gas fired electricity generation. In this scenario the consumption of natural gas in electricity generation in APEC is projected to fall by 22 per cent relative to the reference case at 2030, while the consumption of steaming coal in electricity generation is projected to fall by 14 per cent relative to the reference case at 2030 (figures 27 and 28).

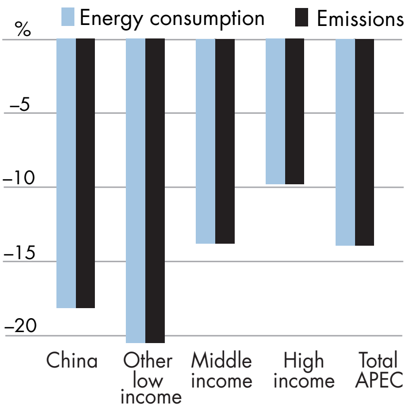
33 Fossil fuel consumption in electricity generation in APEC under the high technology scenario with accelerated adoption, 2030

	Reference case		**High technology with accelerated adoption**	
	2002 a	**2030**	**2030**	**Savings at 2030**
	Mtoe	Mtoe	Mtoe	Mtoe
Brown steaming coal	91.8	87.2	78.2	–9.1
Black steaming coal	1 065.3	1 774.9	1 528.0	–246.9
Oil	134.6	98.1	95.2	–2.9
Natural gas	480.0	917.1	716.1	–201.1
Total	1 771.7	2 877.4	2 417.4	–460.0

a IEA (2004a).

28 Change in APEC black steaming coal fired electricity generation at 2030

High technology development scenario with accelerated adoption relative to reference case



In the steel industry, the accelerated adoption of the advanced steel production technologies successfully commercialised in the high technology development scenario is projected to lead to increased steel production relative to the reference case, while also halving the growth in energy consumption by the steel industry relative to the reference case (table 34).

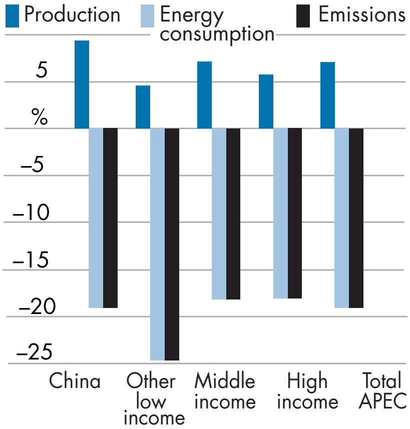
These efficiency improvements are projected to be significant for both steel process routes, with the energy efficiency of electric arc furnace based steel production improving by 26 per cent relative to the reference case at 2030 in this scenario and the energy efficiency of integrated steel production improving by 20 per cent in this scenario relative to the reference case at 2030 (figures 29 and 30). As in the accelerated adoption scenario, these efficiency improvements are strongest in economies that would not otherwise have introduced the most energy efficient steel production technology. In China, for example, the

34 Average annual growth in output and energy consumption in the steel industry in APEC under the high technology development scenario with accelerated adoption, 2002–30

	Reference case		**High technology development with accelerated adoption**	
	Output	**Energy consumption**	**Output**	**Energy consumption**
	%	%	%	%
China	4.0	2.9	4.1	2.0
Other low income	5.9	4.6	6.0	3.5
Middle income	2.1	0.6	2.3	0.0
High income	0.5	0.0	0.5	–0.8
APEC	2.4	1.6	2.5	0.8

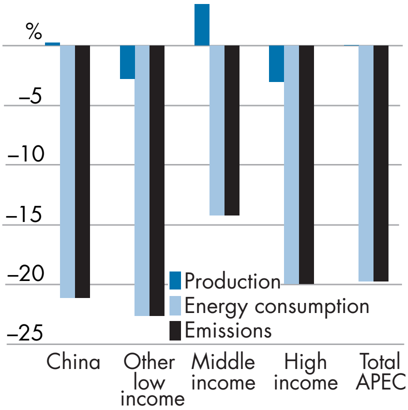
29 Change in APEC electric arc furnace based steel mills at 2030

High technology development scenario with accelerated adoption relative to reference case



30 Change in APEC integrated steel making processes at 2030

High technology development scenario with accelerated adoption relative to reference case



energy efficiency of electric arc furnace steel production is projected to improve by 28 per cent relative to the reference case at 2030, while in Japan the energy efficiency of electric arc furnace steel production is projected to improve by around 22 per cent relative to the reference case at 2030.

As in the high technology development scenario, these energy efficiency improvements reduce the cost of steel production throughout the region, which is projected to increase steel demand in APEC by about 25 million tonnes (or 2.3 per cent) relative to the reference case at 2030. Because these developments improve the competitiveness of electric arc furnace steel production relative to integrated steel production, most of this additional steel demand is met by electric arc furnace capacity. As a result, the production of steel in electric arc furnaces is projected to grow more rapidly than in the high technology scenario. In most economies with integrated steel making capacity, the faster growth of electric arc furnace steel production is matched by slower growth in steel production using integrated process routes (figure 30). The exceptions to this trend are in the Russian Federation and, to a lesser extent, China, where the benefits of technology transfer induce greater steel production in both electric arc furnace based and integrated process routes.

8

conclusions

- The rapid development and accelerated diffusion of advanced energy technologies could make an important contribution to sustainable economic development in the APEC region.
- The extent to which this potential can be realised is dependent on two factors: research to develop more advanced technologies; and appropriate institutional settings within each economy to facilitate the uptake of new technologies, including through technology transfer.
- The APEC forum has the potential to be a key player in the transfer and adoption of advanced technologies.

The results from the economic modeling presented in this report indicate that the development and accelerated diffusion of new technologies in the power generation and steel sectors has the potential to significantly reduce growth in energy consumption in APEC economies as well as growth in greenhouse gas emissions. In the electricity sector, these developments have the potential to reduce the growth in fossil fuel consumption in APEC by around 40 per cent over the period 2002–30. In the steel sector, these developments could halve the growth in energy consumption over the period.

Two important conclusions can be drawn from the findings of these scenarios. The first is that research plays an important role in developing more advanced technologies that can improve the efficiency and environmental performance of the power generation and steel making sectors. Within each economy, appropriate incentives are required to facilitate both private and government expenditure on research and development.

Research and development often requires significant investment; the payoff is inherently uncertain; and, in instances where research leads to the development of a successful innovation, there are often long time lags between initial investment and the realisation of a commercial return. These factors can impede both government and private sector investment in research and development if the benefits of successful innovation cannot be captured. For this reason, it is critical for individual economies to establish legal frameworks that protect intellectual property. The greater the coverage, duration and the enforcement of these rights the greater the incentive to invest in the development of advanced energy and environmental technologies.

In addition to establishing appropriate institutions, the role of government in research and development of more advanced technologies may also extend to direct public expenditure. This expenditure may be targeted to the energy sector or more generally, such as the case of national defence or academic research initiatives. The former may be particularly important in economies with large fossil fuel reserves, such as Australia, where there may be significant commercial benefits arising, for example, from the development of new technologies that reduce greenhouse gas emissions.

The second important conclusion that can be drawn from the results is that the transfer of advanced technologies will be important in helping to close the energy efficiency gap between less technologically advanced economies and those that have developed or adopted more advanced technologies. Clearly, the greatest potential to close this gap will be in economies such as China and the Russian Federation that are characterised by electricity generation and steel production plant that is currently operating at relatively low thermal efficiencies. As most economies are not involved in the development of new technologies, the question that remains is how to facilitate the transfer of technology from the innovating economy to the rest of APEC to enable all economies to move to an alternative technology path.

New capital investments provide significant opportunities to adopt advanced technologies. However, investment in the power generation and steel making sectors can be impeded by a number of factors, including the institutional settings in an economy, and uncertainty and risk. Investment will not occur unless governments establish stable, transparent and predictable legal, fiscal, regulatory and trade regimes.

Unfavorable macroeconomic conditions, inappropriate taxation regimes and incomplete pricing of inputs, as well as restrictive trade policies act as disincentives by lowering potential returns and significantly increasing the risk associated with investment. Uncertainty about future returns may impede the adoption of advanced energy technologies if it leads to the postponement of investment, for example, to allow time to collate better information on likely project outcomes.

Facilitating technology uptake

Regional cooperation can be an important driver of technology transfer and adoption. Collaborative and coordinated research efforts and foreign direct investment have been highlighted in this report as mechanisms for economies to access technologies or expertise that would not otherwise have been available. Research and development of new technologies may be enhanced through collaboration if the sharing of intellectual capital avoids the duplication of research efforts and spreads the risk associated with large scale research and development projects. A coordinated research and development effort can also make better use of comparative research advantages in different economies.

Given the large capital cost and risk associated with demonstration projects, a collaborative approach to their funding could be an important driver of technology transfer. The rate of technology transfer and adoption is enhanced as new technologies are shared with participating economies. As long as appropriate intellectual property rights and institutions are in place, this may provide an opportunity to facilitate the deployment of new technologies throughout the broader APEC region.

Trade agreements may also increase the number of economies from which technology may be sourced, as well as allow access to a wider range of technological innovations. A diverse range of technologies on the technology menu is important as it allows more flexibility when making investment decisions. Similarly, for technology transfer to developing economies, trade liberalisation increases the opportunities for return on research and development expenditure. Once a technology has been adopted, learning effects and associated efficiency improvements may reduce the cost of the technology, making it attractive to additional investors and further increasing market share.

Potential role of the APEC forum

The APEC forum has the potential to be a key player in the transfer and adoption of advanced technologies. A priority for APEC has been the cooperative aspects of regional development, including the promotion of energy relationships within the APEC region (APEC 2004b). These relationships include trade in energy products, but extend more broadly to the dispersion of energy technologies and expertise. The APEC forum could also be an important intermediary for the coordination of information on various research efforts, information sources, partnerships and networks to facilitate the dissemination of information on advanced technologies. Facilitating technology transfer and adoption by using the mechanisms developed for regional cooperation can broaden the scope of energy relationships within APEC economies.

Other mechanisms to improve information dissemination and facilitate technology transfer may include the development of best management practices for electricity generation and steel production that are appropriate to each economy's characteristics such as resource endowments, existing capacity and future investment needs; the design and implementation of specific technology transfer plans and actions that are evaluated and refined on an ongoing basis; and the undertaking of a needs assessment that evaluates priorities for technology transfer and available alternatives. Collation of information on the age and structure of existing capital stocks would be useful in research and development planning as it could help identify when and where opportunities for adoption of more advanced technologies exist.

Mechanisms to enhance energy technology transfer and adoption already exist within the APEC forum. The APEC Energy Working Group seeks to maximise the energy sector's contribution to the region's economic and social well being, while mitigating the environmental effects of energy supply and use. Although the mandate of the Energy Working Group is broader than facilitating technology transfer, it does seek to promote a regionwide approach to energy technology development, exchange, application and deployment. This objective extends to addressing impediments to energy infrastructure investment in the region, and to identifying ways to mobilise private capital. The Group also facilitates linkages between government officials, financial sector representatives and energy business representatives (APEC 2004b).

The APEC forum has subgroups that may also facilitate technology transfer and adoption. For example, the Expert Group on Clean Fossil Energy (EGCFE) has the role of gathering and sharing timely information on technical, economic and policy aspects of clean fossil energy and clean technologies within the APEC region (APEC 2004c). This information is used to facilitate and encourage the commercialisation and use of environmentally sound energy technologies and processes and to facilitate cooperative activities, including demonstration projects in APEC economies.

For the APEC region as a whole, the economic and environmental benefits of advanced energy technologies are significant. There are, however, impediments to technology transfer that will need to be addressed in order to reap the potential benefits of technology transfer and adoption. Any attempts to promote the diffusion of technologies will need to address barriers to investment using a comprehensive approach, recognising that impediments will manifest themselves differently in different economies, and that identification and prioritisation of barriers need to be economy specific. Many such barriers to technology transfer could potentially be reduced if governments, acknowledging the economic and environmental benefits of cooperation, worked together to overcome them.

technology in the electricity sector

There are two principal types of fossil fuel power generation: steam turbines and gas turbines. In a steam turbine, coal, oil or natural gas is burned to heat water to produce superheated steam that is used to drive a turbine. Steam turbines can be subcritical, supercritical or ultra supercritical depending on the temperature and pressure of the steam. Modern large steam turbine power generation plants (more than 500 megawatts) can have efficiencies approaching 40–45 per cent. The process is similar when gas turbines are used except, in a simple cycle configuration, fuels are burned to create hot gases to drive the turbine. Gas and steam turbines can be configured consecutively (‘combined cycle’) where waste heat from a gas turbine is used to produce steam to generate additional electricity.

Advanced energy technologies for fossil fired power generation generally fall into two categories: combustion process improvement and emission control. Technologies designed to enhance the combustion process (which not only improves thermal efficiency but also reduces greenhouse gas emissions) include pressurised fluidised bed and integrated gasification technologies. Emission control technologies include flue gas desulfurisation and selective catalytic reduction.

Coal fired technologies

Stokers and stoker cyclone: These technologies combust coarse or crushed coal to drive conventional steam turbines. They can fire coals that are not suited to pulverisation and are employed in some applications to save capital and operating costs at the expense of thermal efficiency.

Pulverised coal (PC): Pulverised coal systems are currently the most widespread coal fired technology in APEC and the world electricity market, accounting for more than 90 per cent of coal fired electricity generation capacity worldwide. Coal is pulverised and fed into burners where it is combusted at high temperature. This process raises high pressure steam that is used to drive a steam turbine and generate electricity. These systems have combustion efficiencies in the order of 35–45 per cent, depending largely on the quality of coal used (IEA 2002b).

The dominant technology for coal fired power generation capacity in APEC is pulverised coal firing with a subcritical boiler. Supercritical power generation plants can achieve higher efficiencies than subcritical power generation plants by operating under higher temperatures and steam pressures. These power plants require higher quality construction materials to cope with more extreme conditions. Supercritical units have thermal efficiencies of around 45 per cent compared with an average of around 36 per cent for subcritical units (AGO 2000b; IEA 2002b).

Supercritical units are now the standard for new power generation plants in many parts of the world and comprise a significant share of generating capacity in Japan, Korea, the Russian Federation and the United States (Coal21 2004). Ultra supercritical (USCPC) units, which can operate at even higher efficiencies of up to 55 per cent (LHV), are being developed in Europe, the United States and Japan.

Pulverised coal systems are adaptable to a wide range of coal qualities but the combustion process may produce high levels of gaseous and particulate emissions if low quality coal is used. However, current and potential future emission reductions can be achieved through the application of power generation plant design features and downstream clean-up processes. Nitrogen oxide emissions can be controlled within the system through the use of low nitrogen oxide burners that allow coal fired power generation plants to reduce nitrogen oxide emissions by up to 40 per cent. Nitrogen oxide emissions can be further lowered, if required, with the use of selective catalytic reduction (SCR). Sulfur oxides and particulate emissions can be controlled by downstream clean-up processes such as flue gas desulfurisation (FGD) (see section ‘Emission control in the electricity sector’ for further discussion).

Fluidised bed combustion (FBC): FBC is currently used in the United States, China and Europe for power generation plants with less than 300 megawatt capacity. Larger units are being tested at a commercial scale. In an FBC plant, crushed coal mixed with limestone is combusted in a suspended bed. The turbulent state of the gas improves combustion, heat transfer and recovery of waste products. Fluidised beds generally have higher capital costs than conventional pulverised coal systems but produce less nitrogen and sulfur oxides although particulate removal and emission control systems can be added depending on emission standards. FBC power generation plants are particularly suited to clean burning of low grade coals and can also be fueled with waste products such as municipal waste and tyres. Thermal efficiency of these power generation plants is around 30–35 per cent. While the efficiency of most fluidised beds used for power generation is similar to that of conventional subcritical PC power generation plant, this technology has better environmental performance when using lower grade fuels.

Pressurised fluidised bed combustion (PFBC): Pressurised fluidised bed combustion is an advanced bed technology that combusts coal at ten to twenty times atmospheric pressure, with the unique advantage of enabling the use of gas turbines for higher cycle efficiency. Exhaust gas from the bed is cleaned to reduce its concentration of particulates prior to expansion through the gas turbine. The steam turbine produces 80–90 per cent of the generated power, and the gas turbine 10–20 per cent. An electrostatic precipitator or baghouse filter may be located upstream of the stack in order to ensure that the particulate concentration of the gas meets local or national emissions requirements.

There are several commercial scale PFBC power generation plants in operation worldwide. PFBC power generation plants have several advantages over other coal technologies including the flexibility to operate successfully with high ash or high moisture coals. They also have low sulfur dioxide and nitrogen oxide emissions, are compact and can be sited within the boundaries of existing power generation plants. The thermal efficiency of PFBC is around 40 per cent and is expected to improve to closer to 45 per cent in the coming decade (Nautilus Institute 1999).

Integrated gasification combined cycle (IGCC): IGCC power generation plants are a relatively new type of technology for power generation, although the technology has been successfully demonstrated in Japan and the United States. In the IGCC process, coal is not combusted but reacted with oxygen and steam to produce a syngas consisting predominantly of carbon monoxide and hydrogen. The syngas is cleaned of impurities and burned in a gas turbine, driving a steam cycle that generates electricity. The exhaust heat is also used to drive a steam cycle, producing additional electricity. Between 60 and 70 per cent of the power comes from the gas turbine and 30–40 per cent from the steam cycle.

IGCC power generation plants allow electricity to be generated at high levels of efficiency, with the combined power generation process boosting thermal efficiency by as much as 25 per cent above conventional coal fired power generation plants (APEC 2001). The thermal efficiency of IGCC power generation plant is around 43 per cent but improvements of up to 7 percentage points are possible in the foreseeable future (USDOE 2001).

Further, carbon dioxide can be captured at a lower cost from the high pressure and concentrated syngas from an IGCC power generation plants than from the flue gas of conventional pulverised coal fired power stations. IGCC systems also produce less solid waste and lower emissions of sulfur dioxide and nitrogen oxides than conventional PC power generation plants.

IGCC systems use relatively small volumes of cooling water and are desirable if power stations are located in areas lacking adequate water. IGCC power generation plants can also be used for the co-production of hydrogen for use in commercial purposes such as in the manufacture of chemicals and liquid fuels. The sale of hydrogen or syngas to produce these products has the potential to offset some of the cost of electricity generation using IGCC power generation plants (Coal21 2004).

Lignite drying: Lignite drying allows brown coal to be used in IGCC power generation plants, where an integrated drying process is not already employed, by reducing the water content of brown coal. This results in an increase in combustion efficiency and reduces greenhouse gas intensity to a level that can be similar to subcritical PC power generation plants that use black coal. A number of different technologies are being tested, including integrated drying gasification combined cycle (IDGCC) power generation plants. These power generation plants may be able to operate at efficiencies of up to 60 per cent but demonstration is required to further reduce costs and improve reliability to a commercial level (AGO 2000b; Coal21 2004).

Ultra clean coal (UCC): Ultra clean coal is a chemically pulverised coal product that is sufficiently pure to be used as a replacement for natural gas in high efficiency gas turbine generators. UCC fed directly into a gas turbine combined cycle power generation plant can operate at thermal efficiencies of greater than 52 per cent (Coal21 2004). Ultra clean coals are not considered substitutes for conventional coal in traditional power generating systems and are instead used as alternatives in heavy fuel oil and gas turbines. Ultra clean coals are cost competitive with these fuels on an energy equivalent basis (Coal21 2004). The high efficiency rate compared with conventional coal power generation plants represents a potential reduction in greenhouse gas emissions.

Gas and oil fired technologies

Internal combustion engines: Internal combustion engines are well proven, reliable equipment that are commonly used in remote locations such as islands and rural areas, or even for peaking power applications.

Subcritical and supercritical steam: Conventional subcritical and supercritical steam boilers with steam turbines are the most common existing technology for large scale gas and oil fired power generation plants in developed APEC economies.

Simple cycle: Simple (or open) cycle combustion turbine power generation plants use a compressor to compress the inlet air upstream of a combustion chamber. The fuel is ignited to produce a high temperature, high pressure gas that enters and expands through the turbine section. The combustion gases in a gas turbine power the turbine directly, rather than requiring heat transfer to a water/steam cycle to power a steam turbine. The turbine section powers both the generator and compressor. The combustion turbine's energy conversion typically ranges between 30 and 35 per cent efficiency as a simple cycle (LHV).

Natural gas combined cycle (NGCC): NGCC (or combined cycle gas turbines, CCGT) power generation plants are an established technology that now accounts for more than 50 per cent of the worldwide market for new electricity generating capacity. In an NGCC power generation plant, natural gas is combusted in a gas turbine and the waste gases in the turbine are recovered and used to raise steam that drives a steam turbine generating additional electricity. Thus electricity is produced both from the gas turbine shaft and the steam turbine improving the overall efficiency of the power generation plant. NGCC power generation plants have world's best practice thermal efficiencies of around 50 per cent and improvements in gas turbine design are expected to raise this efficiency over time (IEA 2002b).

NGCC power generation plants have the lowest carbon dioxide emissions of all fossil fuel based technologies because of the low carbon content of natural gas and the high efficiency of the power generation plants. Natural gas is free of sulfur dioxide and NGCC technology reduces emissions of nitrogen oxides and particulates. The reduction in greenhouse gas emissions associated with NGCC compared with other technologies makes it an attractive option in economies where there are, or are expected to be, greenhouse gas emissions limits (IEA 2004b).

Combined heat and power (CHP): CHP (or cogeneration) plants use heat for electricity generation and for another form of useful thermal energy (steam or hot water) for manufacturing processes or central heating. CHP cogeneration plant is more commonly associated with gas and oil combustion technologies than with coal. Internal combustion engines, steam boilers and gas turbines are all applicable to cogeneration of electricity and steam, although fuel cells and micro turbines are driving the further development and adoption of CHP systems.

There are two types of CHP systems. First, where a manufacturing process uses high temperature steam first and a waste heat recovery process recaptures the unused energy and uses it to drive a steam turbine to generate electricity. Common sources of waste heat include district heating/cooling and industrial processes. Second, where waste heat from electricity generation is used for another purpose such as space heating.

Combined heat and power generation plants have a higher total efficiency as an integrated system than if there were two separate systems. While efficiencies from this technology can be as high as 85 per cent, the biggest challenge is locating power production near a source of waste heat, or the reverse, and matching the simultaneous demands for electricity and heat throughout diurnal and seasonal variations (APEC 2001).

Emission control in the electricity sector

There are several principal technologies designed to control emissions of particulates, carbon dioxide, sulfur dioxide and nitrogen oxides from power generation plants. Emissions of nitrogen oxides can be abated or controlled by primary measures, such as the use of low nitrogen oxide burners, staged combustion and natural gas afterburning to minimise the formation of nitrogen oxides during combustion, or flue gas treatment technologies. Advanced technologies for controlling carbon dioxide, such as carbon capture and storage, are not yet proven on a commercial scale for electricity generation.

Electrostatic precipitators (ESP) and fabric filters (or baghouses): ESPs and fabric filters are the most widely used particulate emissions control technologies used on coal fired power generation plants. The choice between ESP and fabric filtration generally depends on coal type, power generation plant size and boiler type and configuration. Both technologies are highly efficient particulate removal devices with design efficiencies in excess of 99.5 per cent.

Flue gas desulfurisation (FGD): FGD is common worldwide and has been used to suppress sulfur dioxide emissions for around thirty years. FGD can be retrofitted or incorporated into new plant. The most common method is based on flue gas scrubbing using a limewater slurry (wet scrubbers) that can capture 95 per cent or more of sulfur dioxide in the flue gas before it exits the stack. FGD technologies are continually advancing. Recent developments include the double contact flow scrubber (DCFS) where the limestone slurry contacts with the flue gas twice, ensuring higher desulfurisation efficiency and easier access for maintenance than conventional FGD systems (Japan Corporate News 2004).

Selective catalytic reduction (SCR): SCR is designed to reduce nitrogen oxide emissions. In the SCR process, ammonia is injected into the flue gas and is passed through a catalytic reactor where the ammonia reacts with nitrogen oxides to produce nitrogen and water. The SCR process is suitable for power generation plants that use low sulfur coal and can achieve a reduction in nitrogen oxide emissions of between 80 and 90 per cent. Combined sulfur dioxide/nitrogen oxides removal processes are considered fairly complex and costly. However, emerging technologies have the potential to reduce emissions of sulfur dioxide and nitrogen oxides for less than the combined cost of conventional FGD for sulfur dioxide control and SCR for nitrogen oxide control. Most processes are in the development stage, although some processes are commercially used on low to medium sulfur, coal fired power generation plants.

Carbon capture and storage (CCS): Carbon capture and storage is an advanced technology for reducing carbon dioxide emissions from fossil fuel fired power generation plants beyond that attainable through increases in thermal efficiency. Carbon may be captured from the electricity generation process in a number of ways and the carbon placed in a long term storage facility such as an underground aquifer. There are three generic approaches to capturing carbon dioxide from a power generation plant:

- Post-combustion capture, where carbon dioxide is captured from combusted products in the power generation plant flue gas. Current post-combustion technologies involve chemical or physical solvent scrubbing systems. Carbon dioxide may also be captured using cooling and condensation (cryogenics), membranes or adsorption techniques.
- Pre-combustion capture, which reduces the carbon content of fossil fuels and produces a carbon dioxide rich byproduct. The carbon dioxide is separated using adsorption or absorption methods and can be used, along with the remaining hydrogen, in other industrial processes.
- Oxyfuel combustion, where fuel is burnt in oxygen with recycled carbon dioxide rich flue gas to increase the carbon dioxide concentration prior to capture.

Capture and compression technologies are energy intensive and result in more fuel being used per unit of output. Consequently, reductions in thermal efficiencies of up to 10 percentage points are possible. Increased costs arise through reduced overall power generation plant efficiency combined with increased capital and operating costs. These technologies are still in the early stages of development and there is significant uncertainty about investment costs for commercial scale projects (DTI 2004).

Emerging technologies for coal and gas fired electricity generation

Research expenditure on electricity generation technologies is generally aimed at developing or refining zero carbon dioxide emitting fossil fuel technologies. These technologies are designed to reduce carbon dioxide emissions beyond what is achievable through increases in thermal efficiency. Much of this research is focused on refining IGCC technology at a commercial scale, and developing fuel cells, and carbon capture and storage technologies.

Oxyfuel combustion is a near zero emission technology that can be used with conventional supercritical and ultra supercritical PC fired power generation plants. Coal is burnt in a mixture of oxygen, rather than air, and recycled flue gas in order to increase the concentration of carbon dioxide in the flue gas to facilitate capture. While this technology has not been demonstrated, it has the potential to make carbon dioxide less costly to capture from conventional PC fired power generation plants and could provide a viable retrofit option for existing capacity, or a ‘carbon capture ready’ option for new PC fired power generation plants. The technology is currently very expensive both in terms of capital cost and energy consumption. It may, however, become viable at a commercial scale within the next ten to twelve years (Coal21 2004).

Advanced power generation systems of the future could also include fuel cells and magnetohydrodynamics (MHD), two technologies still in the early development stage. Fuel cells allow hydrogen from natural gas, methanol or coal gas to react electrochemically with oxygen from the air to generate electricity. The theoretical efficiency of this technology is 60 per cent and the system can achieve near zero emissions with carbon dioxide capture and storage, although the capture process will reduce efficiency. The use of fuel cells has been demonstrated at the 2 megawatt size and plans are under way to use hydrogen from coal gasification in this and other technologies.

In a coal fired magnetohydrodynamics system, coal is burned to form an extremely hot gas or plasma. This is given an electric charge by adding a seed compound such as potassium salt. When the charged gas is passed through a strong magnetic field, electricity is produced. Heat from the combustion gases is also used to produce electricity using a conventional steam turbine (Coal21 2004).

Electricity generation costs

Capital and operating costs are a major driver of technology choice. The costs of electricity generation are a function of the fuel cost, the capacity of the power generation plant, efficiency of the technology employed and the cost of financing. Government policy may also affect the price of electricity generation if taxes, such as carbon taxes, or subsidies are used to influence investment decisions. A summary of capital and generation costs for a range of available electricity generation technologies is provided in table 35. There is some variation in costs reported in the literature, reflecting differences in the assumptions of these key factors. Costs detailed in this report are from a range of sources and are representative costs from a variety of economies. Average thermal efficiencies for the technologies are also presented, as well as emissions of carbon dioxide.

The costs (other than fuel) and operational characteristics of new technologies are expected to improve over time. The cost of new technologies varies between economies and will be influenced by the availability, quality and price of fuel, the stock of knowledge in an economy and capital costs. For the newest technologies, capital costs are initially high but are expected to decline as more units are built. The maturity of the technology is also likely to influence regional cost differentials. The cost of building the first IGCC power generation plant in China, for example, may be more expensive than building the same power generation plant in the United States because China is a new business environment for this technology. However, over time the cost of building IGCC in China could decline relative to that in the United States after a transition period as the cost of raw materials and labor is likely to be cheaper than in the United States. Further, some components of the technology may be imported initially but could be produced domestically when the technology becomes established (Nautilus Institute 1999).

Gas fired power generation plants have many advantages over coal fired power generation plants. When compared with coal fired power generation plants generally, combined cycle gas turbines (NGCC) are recognised as being cheaper to build per kilowatt of electricity output, quicker to construct, producing fewer harmful greenhouse gas emissions, offering a higher energy conversion efficiency, occupying less space, and having other

35 Estimated costs and thermal efficiencies of power generation plants

Technology	Average efficiency	Total plant capital cost	Power generation cost	Carbon dioxide emissions
	% LHV	US$/kW	USc/kWh	g/kWh
Subcritical pulverised coal	36	1 095–1 150	4.0–4.5	766–789
Supercritical pulverised coal	45	950–1 350	3.5–3.7	722
Ultra supercritical pulverised coal	45	1 160–1 190	4.2–4.7	
Fluidised bed combustion	30–35	1 000–1 600	3.3	717
Pressurised fluidised bed combustion	39	1 150–1 650		
Integrated gasification combined cycle	42–44	1 100–1 600	3.9–5.0	710–750
Integrated dewatered gasification combined cycle	42		2.3–4.0	810
Gas simple cycle	30	300–600		
Gas subcritical steam turbine	37			
Gas supercritical steam turbine	40			
Natural gas combined cycle	50	400–700	3.4–6.8	344–430

Sources: USDOE (2001); APEC (2001); IEA (2002a, 2004c); AGO (2004a); DTI (2004).

advantages such as the ability to ramp electricity production up and down rapidly. Further, it is likely that only small advances in the efficiency of conventional coal fired technologies will be made over the next ten years compared with those for NGCC.

While NGCC power generation plants have lower capital costs compared with a coal fired power generation plant, they have higher operating costs driven mainly by fuel costs. There are also classic economies of scale in turbine efficiency and cost for NGCC, and for power generation plants more generally, with larger units generally having higher efficiencies and costing less per unit of capacity (ACIL Tasman 2003). There will also be cost savings during manufacture if the technology can be mass produced and this may change the relative capital costs of technologies over time. The competitiveness of NGCC power generation plants is heavily dependent on the price of fuel as fuel costs account for 60–70 per cent of total electricity generation cost. This is considerably higher than that of coal and other fuel sources that can range between 0 and 40 per cent of power generation cost. Consequently, equal increases in the prices of different fuels for electricity generation would have a more serious impact on the economics of NGCC than they would have on other technologies (IEA 1999).

The costs of the two most common post-combustion emission control technologies, FGD and SCR, are reasonably well known as they have been available for many years. Costs do not vary significantly with power generation plant size and figures of US$204/kW for FGD and US$82/kW for SCR are commonly used for a 500 megawatt power generation plant (EIA 2002; APERC 2003). Natural gas power generation plants have an advantage because no sulfur or particulate control systems are required, nor are systems for the control of nitrogen oxides in many economies. For coal fired power generation plants when emissions control limits require sulfur removal to exceed 95 per cent, IGCC power generation plants become increasingly competitive compared with conventional PC fired power generation plants with FGD.

B

appendix

technology in the iron and steel sector

Steel production today is dominated by the integrated blast furnace production route and the electric arc furnace based route. Most of the remainder is produced by older steel making processes, including the open hearth furnace and the Bessemer furnace, which although obsolete have not been entirely phased out in all economies. Finally, a small portion of current steel output is produced using smelt reduction technologies, such as the Corex process, which are relatively new technologies that are being developed to overcome some of the limitations of the blast furnace.

Integrated steel production

Integrated steel making is centred on the blast furnace, in which agglomerated iron ore, coke and a small amount of flux elements are reduced by reducing gases generated as the descending coke and iron comes into contact with the upward moving hot blast air and other fuels. For optimal operation of the blast furnace, the coke and agglomerated iron ore, which are usually made on site in coke ovens and sinter plants respectively, must conform to strict specifications to ensure that they mix appropriately with the reducing gases in the blast furnace.

After being tapped from the bottom of the blast furnace while still molten, reduced iron ore, or pig iron, along with a small portion of steel scrap, is transferred to a basic oxygen furnace, where oxygen is blown through the iron to separate the carbon and other impurities from the metal. This process leaves molten steel, which is poured into a ladle, where it can be blended with other materials to form alloy steels, before being cast into shape. The steel is then continuously cast into slabs, blooms or billets according to its desired use, before being passed through a hot rolling mill, where it is reheated and rolled to achieve a desired width and shape.

After hot rolling, some steel products such as plates, bars and sections are ready for sale and use while other products require further treatment in a cold mill. In a cold mill, hot rolled coil is cleaned and further rolled to form either sheet or tinplate. Steel sheet can be galvanised with zinc and/or other substances for subsequent use in car bodies or white goods, while tinplate is cleaned and coated with tin for use in the packaging industry.

Energy use

Because of the large number of individual processes involved in this production route, integrated steel mills are also significant energy users, consuming between 19 and 40 gigajoules of energy for each tonne of crude steel produced (de Beer et al. 1998). Most of this energy is consumed in the blast furnace, which at current best practice has a net primary energy consumption of around 12 gigajoules a tonne of crude steel (table 36)(de Beer et al. 1998). Significant amounts of energy are also consumed in the coking and sintering plants and during the refining and shaping stage.

The significant variation in the energy consumption of integrated steel mills is indicative of the large potential energy savings that modern mills have made through process improvements designed to optimise the purchased energy requirement of their operations.

These process improvements have primarily involved the collection and reuse of hot waste gases from the blast furnace, the basic oxygen furnace and the coke ovens; the partial substitution of coke with other fuels, such as pulverised coal and oil, in the blast furnace and the development of better systems to control the fuel mix and operating conditions within the blast furnace. For example, the collection and cleaning of unreacted reducing gases from the blast furnace is estimated to reduce net energy consumption in the blast furnace by around 4.7 gigajoules a tonne of hot metal (IISI 1998).

It is estimated that the coke oven gas, blast furnace gas and oxygen furnace gas captured by the most efficient integrated steel mills is sufficient to power coke ovens, sinter plants, blast stoves and reheating furnaces while also producing enough electricity to meet the mill's electricity requirement (de Beer et al. 1998).

36 **Best practice net energy consumption in an integrated steel plant, by process**

	Net energy consumption
	GJ/t crude steel
Coke oven	1.8
Sinter plant	2.5
Blast furnace	11.8
Basic oxygen furnace	0.3
Refining and casting	0.6
Rolling and shaping	2.1
Total	19.0

Source: de Beer et al. (1998).

Additional emission reduction technologies

In addition to the fuel conservation measures listed above, that have been routinely employed by integrated steel mills seeking to improve efficiency and reduce costs, there are many other energy saving measures that mills could adopt if their objectives were to improve energy efficiency and environmental performance. The most significant of these are coke dry quenching and flue gas desulfurisation.

Coke dry quenching involves using an inert gas (usually nitrogen) to cool the hot coke produced in coke ovens to prevent the coke from oxidising. These hot inert gases are then transferred to a steam boiler, where they can be used to generate steam or electricity for use elsewhere in the steel making process. This process is estimated to result in energy savings of up to 1700 megajoules for each tonne of dry coke quenched relative to the water quenching process generally used to cool coke in the coke oven (IISI 1998). The water quenching process involves using water to cool the coke, which produces steam that is generally lost to the atmosphere.

Flue gas desulfurisation systems are based around the concept of passing waste gases from fossil fuel combustion through an absorption tower containing an absorptive material, typically lime. As the waste gases pass through the lime, dusts containing sulfur particles and other wastes are absorbed by the lime, which in some cases can be reused as gypsum. Flue gas desulfurisation systems can be used to clean the flue gases released at any stage of the steel production process, from coke and sinter production to iron making. These systems typically add both energy and other costs to steel production and are generally used in economies where environmental laws limiting sulfur dioxide emissions are in place.

Electric arc based steel production

Electric arc furnace based minimills are generally smaller, simpler and more flexible operations than integrated steel mills, using fewer process steps to convert steel scrap and, in some cases, scrap substitutes such as direct reduced iron to final steel products. In this process, a charge of steel scrap and scrap substitutes and small amounts of lime are melted by an electric arc in the electric arc furnace. The lime is used to form a slag for capturing impurities that are released from the scrap. The electric arc is generated by passing an electric current through the metal charge and another current through electrodes on the furnace ceiling and then gradually lowering the furnace ceiling until the two currents come into contact. As with the basic oxygen furnace, oxygen can be passed through the electric arc furnace to accelerate the melting process.

In modern 'shaft' furnaces, the metal charge is preheated in a separate vessel by furnace waste gases prior to being deposited in the furnace. After the charge has been melted and the slag removed, the molten steel is usually transferred to a secondary ladle for further refinement. After refinement, the steel is cast into either ingots, slabs of greater than 150 millimetres (mm) in thickness or thin slabs under 50 mm thick, depending on the final steel product to be produced. These slabs then undergo some hot rolling before being sold and used.

Direct reduced iron

Direct reduced iron has emerged as an important input for minimills seeking to improve the quality of their charge and produce higher quality steel products. In 2003, global production of direct reduced iron was 49.5 million tonnes (Midrex 2003). Direct reduction technologies facilitate the reduction of iron ore to a highly metallised product consisting of more than 90 per cent iron at elevated temperatures below the melting point of iron. They achieve this by reacting the carbon and oxides in agglomerated iron ore with reducing gases consisting of either hydrogen and carbon monoxide or just carbon monoxide, depending on whether natural gas or coal is used as the source of the reducing gas.

In the natural gas based processes, such as the Midrex process and the Hylsa process, which produce the vast majority of global direct reduced iron, heated natural gas, steam and recycled waste gases are sent through a gas reformer to produce a gas that is predominantly hydrogen and carbon monoxide. This gas is fed into a reduction shaft, where it flows up and mixes with iron ore that has been fed from the top of the shaft. In the bottom of the shaft, the reduced iron is cooled with cooling gases, which are also recycled in the process.

In the traditional coal based direct reduction processes, coal and agglomerated iron ore are fed into the top of an inclined rotary kiln and reduced through the heat and carbon monoxide resulting from the combustion of the coal and oxygen as it descends through the kiln. The resulting direct reduced iron can then be cooled and briquetted for storage and transport or, if the electric arc furnace is nearby, transported as hot direct reduced iron for hot charging in the electric arc furnace. Hot direct iron is generally transported on conveyors from the plant to the furnace or, if the plant and furnace are further apart, briquetted and transported while the briquettes are still hot. More recently, gravity fed pipeline systems have been developed that can charge hot direct reduced iron at temperatures close to 700 degrees Celcius (Midrex 1999).

Energy use

Energy consumption in electric arc furnace based minimills is affected by a number of factors, including the type of electric arc furnace used, the percentage of direct reduced iron or hot metal in the charge, the technology used to produce the direct reduced iron and the heat of the charged materials. For example, a modern electric arc furnace with scrap preheating can convert a charge of 100 per cent steel scrap to bars or flat products for around 5 gigajoules a tonne of crude steel (de Beer et al. 1998). It is estimated that this scrap preheating reduces electricity consumption by around 80 kWh a tonne of liquid steel (or around 0.7 gigajoules of energy for each tonne of crude steel produced) (IISI 1998).

In general, electricity consumption in the electric arc furnace falls by around 20 kWh for each 100 degrees Celcius increase in the charge temperature (Midrex 1999). However, if a charge of 100 per cent direct reduced iron is used in the same furnace, the total amount of energy consumed in the process would increase to around 18.5 gigajoules a tonne of crude steel, which is similar to the energy consumed by an integrated steel mill operating at best practices (table 37) (de Beer et al. 1998).

Energy consumption in direct reduced iron production varies according to the specific technology being used. Natural gas based technologies such Midrex and Hylsa typically consume about 11 gigajoules of natural gas and 100 kWh of electricity for each tonne of direct reduced iron they produce. Traditional coal based direct reduction technologies such as SL/RN consume around 19 gigajoules of coal for each tonne produced but are able to use some of the surplus reducing gases to generate additional electricity, which results in a net energy consumption of around 15 gigajoules a tonne of direct reduced iron (IISI 1998).

37 Best practice net energy consumption in an electric arc furnace under different charge regimes, by process

	Net energy consumption	
Process	**100 per cent scrap**	**100 per cent DRI**
	GJ/t crude steel	GJ/t crude steel
Ore preparation		1.4
Direct reduction		12.1
Electric arc furnace	3.4	3.4
Refining and casting	0.6	0.6
Rolling and shaping	1.0	1.0
Total	5.0	18.5

Source: de Beer et al. (1998).

Areas of innovation

For a number of years, research and development in the steel industry has focused on three broad areas: steel casting, smelt reduction technologies and new direct reduction technologies. Research on steel casting has aimed to develop technologies capable of casting steel at thinner gauges, thereby reducing the amount of rolling necessary to produce flat steel products.

Developers of smelt reduction technologies have sought to produce pig iron using iron ore fines and non-coking coals, thus reducing the capital costs of integrated steel making by reducing the need for coke ovens, sinter plants and high quality raw materials. Similarly, developers of new direct reduction technologies have also aimed to create processes based on the use iron ore fines and coal. This research has resulted in a number of new steel making technologies that are currently in the early stages of commercialisation and could have an impact on the steel industry over the period to 2030.

Casting technologies

Although the idea of thin gauge casting has been appreciated within the steel industry for many years, it has only been in the past twenty years that the industry has been able to undertake development of thin gauge casting technologies in earnest (Birat 2003). Research into casting technologies over the past twenty years has yielded two important developments: thin slab casting, which was commercialised in 1989 by minimills in the United States seeking to enter the market for flat steel products; and thin strip casting, which was first introduced by stainless steel makers in the 1990s and is now being commercialised by carbon steel makers in the United States and Europe.

Thin slab casting

Thin slab casters are able to cast steel slabs of around 50 millimetres by partially solidifying molten steel in a mould set at the desired slab thickness. Similarly to traditional continuous casting, the slab is vertical on exiting the casting mould and is bent horizontally before entering a soaking furnace, which equalises its temperature in preparation for rolling. In some processes, the hot thin slabs are immediately reduced to around 40 millimetres before entering the soaking furnace. This process is termed liquid core reduction. From the soaking furnace, the slabs are then rolled to final gauge in five to seven hot rolling stands before being cooled and coiled.

Advantages of this process over traditional continuous casting are that the thin slab does not require reheating and does not need to be thinned in a roughing mill before rolling, thus eliminating the need for reheating furnaces and roughing mills as well as the additional energy consumption associated with those processes. It is estimated that converting liquid steel to steel strip using a thin slab caster and hot strip mill requires around 1 gigajoule of energy, which is about 1.3 gigajoules of energy less than that required when producing steel strip with a traditional continuous caster (IISI 1998).

Since 1989, thin slab casting technology has been adopted by minimills that were previously prevented from producing high value flat products by the prohibitive capital and operating costs of producing steel strip from thick slabs. This adoption has also had other effects on minimill operations. For example, in order to meet the quality specifications for some flat steel products, minimills have placed more effort on steel refining and, in some cases, have invested in direct reduction facilities to improve the purity of their charges. These additional investments have increased the optimal scale of operations from between 0.5 and 1 million tonnes of steel a year for purely scrap based minimills to between 1.5 and 2 million tonnes a year for minimills producing higher quality flat products, fundamentally changing the composition of the steel industry (de Beer et al. 1998).

Despite the changes that thin slab casting has brought to the steel industry, it is included as an emerging technology because it has not been widely adopted by the integrated steel mills and has not diffused as widely in the rest of the world as it has in the United States.

Thin strip casting

Thin strip casters cast steel strip of around 1–2 millimetres by pouring liquid steel between two counter rotating casting rolls. The steel begins to solidify as a result of contact with the water cooled rolls, forming an edge which becomes harder as the rolls rotate. The steel strip is formed when the two hard edges from each roll are joined at the closest point between the rolls.

On exiting the rolls, the strip enters a controlled atmosphere to prevent scale formation and is then fed through a pinch roll and directed through one or two hot rolling stands before being cooled and coiled. Thin strip casting represents a significant development in casting technologies, reducing rolling requirements well below those of traditional or thin slab casting.

It is estimated that thin strip casting requires around 0.2 gigajoule of energy for every tonne of strip cast, which is approximately 0.8 gigajoule below that required by thin slab casters and about 2 gigajoules less than the energy used by conventional slab casters and hot strip mills (Wechsler and Ferriola 2002).

As is the case with thin slab casting, thin strip casting will enable smaller producers to make hot rolled coil and enter the flat products market. At this stage, it appears that thin strip casting will be viable for minimills with annual capacities as low as 0.5 million tonnes of steel (de Beer et al. 1998). However, it is uncertain whether thin strip casting will affect the steel industry as immediately as thin slab casting. This is because thin strip casting, unlike thin slab casting, is very different to conventional casting technologies and may be more difficult for steel makers that have not been involved in its development to adopt.

Smelt reduction technologies

Smelt reduction technologies aim to provide a smaller scale, less capital intensive alternative to the blast furnace capable of producing pig iron from raw materials of lesser quality than those required for the blast furnace. Smelt reduction technologies generally split the iron making process in two by employing one vessel, known as the prereduction vessel, in which iron ore is partially reduced by hot waste gases originating from the second vessel, known as the smelt reduction vessel, in which the combustion of coal and oxygen produces enough heat to smelt the prereduced iron ore.

After considerable research, one smelt reduction technology, Corex, was commercialised in 1989 and another two technologies, Finex and Hismelt, are currently in the early stages of commercialisation. Other smelt reduction technologies, such as Dios and CCF, have also been developed but seem unlikely to be commercialised in the near future (Nill 2003).

Corex / Finex

The Corex process is a two vessel smelt reduction process based around the smelter gasifier, in which hot reducing gases formed from the combustion of coal and oxygen melt prereduced iron in a fluidised bed. On exiting the smelter gasifier, these reducing gases are cleaned and cooled before being transferred to the prereduction vessel, which is a shaft furnace for the prereduction of lump iron ore or pellets. Not all of the gas is required to prereduce the iron and the gases exiting the vessel contain a significant amount of energy that can be used for other purposes, such as electricity generation or the production of direct reduced iron. These waste gases can have an energy value of up to 13 gigajoules for every tonne of hot metal produced so their use has a significant bearing on both the economics and the energy consumption of the Corex process (IISI 1998). An additional feature of the Corex process is that the sulfur released by the coal and ore is captured in a solid state in the slag, which limits sulfur emissions from the process to around 10 per cent of those emitted by hot metal production in integrated steel mills (POSCO 2004).

The low degree of gas combustion in the Corex process is associated with a high coal use of around 900 kilograms for each tonne of hot metal produced, which, after crediting for the energy embodied in the waste gases, results in a net energy consumption of between 15.5 and 17.5 gigajoules for each tonne of hot metal produced (de Beer et al. 1998).

Since 1989, a number of Corex plants have been introduced in areas in short supply of coking coal such as India, South Africa and Korea. Further research has focused on adapting the process to accommodate iron ore fines, which has led to the development of the Finex process. In the Finex process, the prereduction of iron ore fines occurs in a fluidised bed. A Finex demonstration plant has been successfully operated by POSCO, a codeveloper of the technology, who is constructing a commercial scale steel making plant capable of producing 1.5 million tonnes of hot metal a year. This steel plant is scheduled to begin producing hot metal in 2006. There are plans for further development over the next ten years if the technology is successfully demonstrated at a commercial scale (Chosun Ilbo 2004).

Hismelt

The Hismelt process is a two vessel smelt reduction process developed by Rio Tinto and partners to produce pig iron using non-coking coals and lower quality, high phosphorous iron ore fines. In the process, iron ore fines preheated in a fluidised bed, fluxes for slag formation and non-coking coals are injected directly into a molten bath in the smelt reduction vessel. The reducing gases are generated by the reaction of the coal with the molten iron. Unlike in the Corex process, these gases are combusted in the smelt reduction vessel by a hot blast of oxygen enriched air injected from the top of the vessel, which generates additional energy for the smelting process.

Hot offgases from the smelt reduction vessel and the ore preheating vessel are cleaned and, because they have a relatively low calorific value, enriched with natural gas before being used to preheat the ore, to heat the hot blast stoves and to generate electricity for the process. At the end of the process, the hot metal is transferred to a desulfurisation facility, where its sulfur content is reduced by reaction with manganese and lime.

Because the reducing gases are combusted in the smelt reduction vessel, the Hismelt process requires around three quarters as much coal as the Corex process and generates less than half as much export gas. Energy consumption by the Hismelt process is estimated at around 14–15 gigajoules for each tonne of hot metal produced (de Beer et al. 1998).

Commercialisation of the Hismelt process is progressing with the construction of a steel making plant capable of producing 800 000 tonnes of hot metal a year at Kwinana in Western Australia (Hismelt PER 2002). The steel making plant is scheduled to reach full production capacity by mid-2006 (Rio Tinto 2004).

Cyclone converter furnace

The cyclone converter furnace (CCF) is one of the few single vessel smelt reduction technologies in development. In this process, iron ore fines and oxygen are injected tangentially to an ore melting cyclone above the smelter and are almost immediately reduced and melted by the reducing gases moving up through the smelter. The liquid ore trickles down the sides of the furnace, which are water cooled to prevent the material from sticking to its sides, before collecting as molten metal at the bottom of the furnace. Coal and oxygen are directly injected to the molten metal, where they combust to produce the reducing gases. The offgases are cooled in a waste heat boiler and cleaned, which produces steam and a cleaned gas product worth about 5 gigajoules of energy for each tonne of hot metal that can be used outside the steel plant (de Beer et al. 1998).

The high degree of offgas combustion, along with the efficiencies gained by using one vessel to execute the process, means that the CCF process is less energy intensive than the other smelt reduction processes in development. It is estimated that the CCF consumes around 650 kilograms of coal and 670 kilograms of oxygen, which, assuming the energy produced from the offgases is used elsewhere, results in the process consuming between 13 and 14 gigajoules of energy for each tonne of hot metal produced (de Beer et al. 1998).

Despite the inherent attraction of the process, the development of CCF technology has stalled since 1999 when the developers decided not to construct a commercial scale demonstration steel plant because of the associated large financial risks (Nill 2003). Although no plans for further development of the technology have been announced, the CCF process has been included in this report because it is the most energy efficient smelt reduction technology and, as a single vessel process, may be considered a forerunner of future smelt reduction technologies.

Direct reduction technologies

The emergence of the direct reduced iron – electric arc furnace steel production route as an alternative to minimills seeking to produce higher quality steel products has led to significant developments in direct reduction technologies. These developments have aimed to improve the competitiveness of direct reduced iron relative to pig iron and high quality scrap, which has historically been poor in areas without cheap natural gas supplies, or scarce scrap and coking coal supplies.

Accordingly, the processes developed have been either coal based, iron fines based or have aimed to produce a higher quality iron product.

The main processes under development include Fastmet and its offspring, Itmk3, which are based around the reduction of coal–iron pellets in a rotary hearth furnace; Circofer and Circored, which are coal and gas based processes using fluidised bed technology to reduce iron ore fines; Finmet, which is a gas based process also using fluidised bed technology to reduce iron ore fines; and Iron Carbide, which is a gas fired process using fluidised technology to produce direct reduced iron with a higher carbon content than regular direct reduction iron.

Fastmet and Itmk3

In the Fastmet process, low grade iron ore fines or iron bearing wastes are mixed with pulverised coal and pelletised. These ‘green pellets’ are fed into a doughnut shaped rotary hearth furnace, where they are reduced at temperatures of around 1350 degrees Celcius as they travel around the furnace.

The heat in the furnace is controlled by fuel fired burners, which complement the heat generated by the combustion of carbon monoxide within the pellets. The offgases from this process are cleaned and used to generate heat for drying the pellets before they enter the furnace and for additional heat within the furnace. As the gases are water cleaned, they can also be used to produce electricity for the process. The final iron product can then be used as a feedstock for electric arc or basic oxygen furnaces or charged to an electric iron making furnace and converted to a product that is very similar to pig iron.

The Fastmet process consumes around 15.9 gigajoules of energy for each tonne of direct reduced iron produced, which is significantly more than that consumed by the Midrex and Hylsa processes. As the process is coal based, greenhouse gas emissions associated with it are higher than those from gas based direct reduction processes (IISI 1998). Fastmet’s primary environmental benefit is that it enables steel makers to convert iron bearing wastes, which are generally stored on site in landfills and in some economies are subject to environmental legislation, into a valuable iron feedstock. At present, two commercial scale Fastmet plants are operating in Japan.

Like the Fastmet process on which it is based, the Itmk3 process also employs the reduction of green pellets in a rotary hearth furnace. However, Itmk3 goes further than Fastmet by melting the metal after it has been reduced, which separates the slag from the metal and results in a product with a carbon content closer to pig iron than standard direct reduced iron.

There are no offgases from the process. Advantages of this product over standard direct reduced iron are that Itmk3 can be charged directly to a basic oxygen furnace or electric arc without requiring further treatment or dilution with other feed materials. Also, as the slag is separated from the iron in one process, it is a lighter product and can be shipped more cheaply than standard direct reduced iron.

Results from a 25 000 tonne a year demonstration steel plant in the United States indicate that the process produces less greenhouse gas emissions than both integrated steel makers and standard direct reduction processes for each tonne of cast steel (Nunn, Wibberley and Scaife 2001). It is expected that the technology will be commercialised with the construction of a 500 000 tonne plant scheduled to begin in 2005 (USDOE 2004b).

Finmet

The Finmet process uses a fluidised bed drier and four fluidised bed reactors to produce direct reduced iron from iron ore fines and a hydrogen rich reducing gas derived from natural gas. The reducing gases, which consist of reformed natural gas mixed with cleaned waste gases processed in a carbon dioxide absorber, are initially fed into the fourth fluidised bed reactor, where they mix with the prereduced iron from the third reactor to complete the direct reduction process. The reducing gases pass from the fourth reactor, through the third, second and first reactors, losing chemical energy as they come into contact with the iron ore at each stage, before finishing up in the fluidised bed drier, which initially dries the iron ore fines prior to their entry to the first reduction reactor. Finally, the direct reduced iron is briquetted for storage and transport.

The Finmet process uses around 14 gigajoules of energy for each tonne of direct reduced iron produced, which is less than that used by the rotary hearth direct reduction processes and, after accounting for the approximately 2 gigajoules of energy embodied in pellet production for each tonne of direct reduced iron, is comparable with conventional gas based direct reduction processes (IISI 1998). As a result of the high level of gas use within the reactors, no waste gases are produced in the process.

The Finmet process was commercialised in 2000 with the commissioning of a facility at Port Hedland in Australia capable of producing 2.5 million tonnes of hot briquetted iron a year (www.steel-technology.com 2004). Since then, another Finmet plant has opened in Venezuela. As of December

2004 the plant in Venezuela was operational, while the plant in Australia was under care and maintenance (www.topix.net 2004; BHP Billiton 2004b).

Circored and Circofer

The Circored and Circofer processes are also fluidised bed based processes for converting iron ore fines to direct reduced iron with reducing gases generated from natural gas and coal respectively. The processes use a circulating fluidised bed to preheat the ore and a stationary fluidised bed for the final reduction. As with the Finmet process, reducing gases are initially fed to the final reduction reactor before passing through to the preheating reactor. Again, no waste gases are generated through these processes.

Both processes are highly energy efficient, with the Circored process estimated to consume around 12.5 gigajoules for each tonne of direct reduced iron it produces and the Circofer plant estimated to consume around 11.7 gigajoules for each tonne of direct reduced iron (IISI 1998). When the energy used in pelletising iron ore for the conventional direct reduction processes is accounted for, the total energy consumed to produce direct reduced iron by the Circored and Circofer processes is probably slightly below that used in the conventional natural gas based direct reduction processes.

To date, one Circored plant with a production capacity of 500 000 tonnes of hot briquetted iron a year has been built in Trinidad and Tobago (Midrex 2003). The plant operated for one year and was closed in 2001 in response to low global scrap and direct reduced iron prices; it was reopened in late 2004 (Outokumpu Technology 2004).

C appendix

scenario results, by economy

Australia

		Reference case		HT	AA	HTAA
		2002	**2030**	**2030**	**2030**	**2030**
Total energy consumption						
Brown coal	Mtoe	15.2	17.9	15.9	17.3	15.7
Black coal	Mtoe	33.7	51.8	47.8	51.0	46.9
Petroleum	Mtoe	34.7	65.3	65.5	65.3	65.5
Gas	Mtoe	20.6	52.2	50.3	52.0	50.2
Other	Mtoe	1.5	4.3	4.3	4.3	4.3
Total	Mtoe	105.7	191.3	183.7	189.9	182.5
Greenhouse gas emissions						
Brown coal	Mt CO_2e	53.8	63.1	56.3	61.3	55.5
Black coal	Mt CO_2e	121.8	185.5	171.0	182.8	167.8
Petroleum	Mt CO_2e	108.6	192.1	192.5	192.2	192.6
Gas	Mt CO_2e	44.7	111.5	103.7	110.6	103.0
Total	Mt CO2e	328.9	552.3	523.5	546.9	518.9
Energy consumption in electricity, by fuel						
Brown coal	index	1.00	1.16	1.03	1.13	1.01
Steaming coal	index	1.00	1.56	1.43	1.54	1.40
Petroleum	index	1.00	0.96	0.90	0.95	0.89
Gas	index	1.00	2.28	1.89	2.23	1.85
Total	index	1.00	1.53	1.37	1.50	1.34
Energy consumption in steel, by technology						
Blast furnace	index	1.00	1.22	1.01	1.17	0.97
Electric arc furnace	index	1.00	1.25	1.05	1.18	1.00
Total	index	1.00	1.22	1.01	1.17	0.97

continued

Canada

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	16.9	16.5	15.2	16.3	15.0
Black coal	Mtoe	12.6	13.8	13.0	13.6	12.9
Petroleum	Mtoe	85.9	131.8	131.9	131.8	131.9
Gas	Mtoe	75.3	134.5	126.1	133.2	125.4
Other	Mtoe	48.1	63.3	63.2	63.3	63.2
Total	Mtoe	238.7	360.0	349.4	358.2	348.3
Greenhouse gas emissions						
Brown coal	Mt CO_2e	64.7	63.4	58.5	62.5	57.7
Black coal	Mt CO_2e	56.5	57.9	55.0	57.4	54.4
Petroleum	Mt CO_2e	260.1	341.8	341.3	341.7	341.3
Gas	Mt CO_2e	151.7	508.7	435.8	497.2	429.7
Total	Mt CO_2e	533.0	971.8	890.6	958.8	883.0
Energy consumption in electricity, by fuel						
Brown coal	index	1.00	0.98	0.90	0.96	0.89
Steaming coal	index	1.00	1.04	0.99	1.03	0.97
Petroleum	index	1.00	1.00	0.93	0.99	0.92
Gas	index	1.00	3.45	2.78	3.34	2.72
Total	index	1.00	1.49	1.30	1.46	1.28
Energy consumption in steel, by technology						
Blast furnace	index	1.00	0.76	0.64	0.73	0.61
Electric arc furnace	index	1.00	0.92	0.79	0.88	0.76
Total	index	1.00	0.78	0.66	0.75	0.63

continued

Chile

		Reference case		HT	AA	HTAA
		2002	**2030**	**2030**	**2030**	**2030**
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	2.7	6.6	6.3	6.5	6.1
Petroleum	Mtoe	9.5	26.2	26.1	26.2	26.1
Gas	Mtoe	6.2	17.7	17.7	17.6	17.7
Other	Mtoe	2.0	5.8	5.8	5.8	5.8
Total	Mtoe	20.4	56.4	55.9	56.1	55.7
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	14.8	33.9	32.6	33.3	31.9
Petroleum	Mt CO_2e	35.6	93.6	93.6	93.6	93.6
Gas	Mt CO_2e	23.0	91.0	74.9	87.5	72.5
Total	Mt CO_2e	73.4	218.5	201.2	214.4	198.0
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	1.74	1.60	1.66	1.51
Petroleum	index	1.00	0.51	0.51	0.51	0.51
Gas	index	1.00	4.00	3.28	3.85	3.17
Total	index	1.00	2.86	2.42	2.74	2.33
Energy consumption in steel, by technology						
Blast furnace	index	1.00	2.59	2.07	2.47	1.96
Electric arc furnace	index	1.00	4.89	3.76	4.56	3.49
Total	index	1.00	2.73	2.17	2.60	2.05

continued

China

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	707.2	1368.7	1 274.8	1 307.3	1 213.5
Petroleum	Mtoe	241.4	723.2	726.0	723.7	726.6
Gas	Mtoe	31.9	182.4	159.4	176.5	156.0
Other	Mtoe	30.7	143.0	141.8	142.5	141.4
Total	Mtoe	1 011.1	2 417.3	2 302.0	2 350.0	2 237.4
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	2 638.5	6 059.4	5 700.9	5 768.7	5 404.5
Petroleum	Mt CO_2e	727.0	1 565.0	1 568.3	1 565.3	1 568.7
Gas	Mt CO_2e	33.4	233.2	192.7	223.1	186.8
Total	Mt CO_2e	3 398.9	7 857.7	7 461.9	7 557.1	7 160.0
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	1.95	1.77	1.79	1.60
Petroleum	index	1.00	0.81	0.80	0.81	0.80
Gas	index	1.00	45.78	35.68	43.29	34.22
Total	index	1.00	2.23	1.98	2.05	1.81
Energy consumption in steel, by technology						
Blast furnace	index	1.00	2.20	1.86	2.06	1.73
Electric arc furnace	index	1.00	2.37	2.05	2.22	1.92
Total	index	1.00	2.21	1.87	2.06	1.74

continued

Hong Kong, China

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	5.4	10.5	9.6	10.3	9.4
Petroleum	Mtoe	8.3	14.1	14.0	14.1	14.0
Gas	Mtoe	1.9	3.6	3.2	3.6	3.2
Other	Mtoe	0.7	0.3	0.3	0.3	0.3
Total	Mtoe	16.3	28.5	27.2	28.3	27.0
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	20.1	39.3	35.9	38.7	35.1
Petroleum	Mt CO_2e	12.0	19.1	19.0	19.1	19.0
Gas	Mt CO_2e	7.1	14.0	12.3	14.0	12.3
Total	Mt CO_2e	39.2	72.4	67.2	71.7	66.4
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	1.96	1.79	1.93	1.75
Petroleum	index	1.00	1.86	1.61	1.83	1.58
Gas	index	1.00	1.97	1.71	1.97	1.71
Total	index	1.00	1.96	1.77	1.94	1.74
Energy consumption in steel, by technology						
Blast furnace	index	–	–	–	–	–
Electric arc furnace	index	–	–	–	–	–
Total	index	–	–	–	–	–

continued

Indonesia

		Reference case		HT	AA	HTAA
		2002	**2030**	**2030**	**2030**	**2030**
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	18.0	70.7	63.8	65.3	58.5
Petroleum	Mtoe	56.1	171.3	171.3	171.8	171.8
Gas	Mtoe	33.0	91.6	86.4	90.0	85.3
Other	Mtoe	6.2	17.6	17.2	17.5	17.1
Total	Mtoe	113.3	351.2	338.7	344.5	332.7
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	49.2	203.0	188.1	192.0	177.3
Petroleum	Mt CO_2e	171.1	514.0	514.0	515.1	515.3
Gas	Mt CO_2e	21.0	66.8	60.2	64.2	58.5
Total	Mt CO_2e	241.3	783.8	762.3	771.3	751.0
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	3.96	3.45	3.61	3.12
Petroleum	index	1.00	1.21	1.13	1.19	1.12
Gas	index	1.00	4.52	3.50	4.14	3.29
Total	index	1.00	3.39	2.88	3.12	2.65
Energy consumption in steel, by technology						
Blast furnace	index	–	–	–	–	–
Electric arc furnace	index	1.00	3.57	2.80	3.29	2.55
Total	index	1.00	3.57	2.80	3.29	2.55

continued

Japan

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	100.0	101.6	92.2	100.3	91.2
Petroleum	Mtoe	255.5	289.7	290.0	289.7	290.0
Gas	Mtoe	66.4	95.3	88.7	95.5	88.8
Other	Mtoe	87.9	118.3	117.5	118.2	117.4
Total	Mtoe	509.8	605.0	588.5	603.7	587.4
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	354.1	357.6	324.8	353.3	321.4
Petroleum	Mt CO_2e	672.7	761.2	761.5	761.0	761.3
Gas	Mt CO_2e	135.5	184.1	166.3	183.8	166.1
Total	Mt CO_2e	1 162.4	1 302.8	1 252.6	1 298.1	1 248.8
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	1.07	1.01	1.07	1.01
Petroleum	index	1.00	0.66	0.66	0.66	0.66
Gas	index	1.00	1.42	1.26	1.42	1.25
Total	index	1.00	1.12	1.03	1.12	1.03
Energy consumption in steel, by technology						
Blast furnace	index	1.00	0.93	0.78	0.90	0.76
Electric arc furnace	index	1.00	0.77	0.67	0.75	0.65
Total	index	1.00	0.92	0.77	0.89	0.75

continued

Korea

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	46.0	75.2	68.3	74.1	67.4
Petroleum	Mtoe	102.0	184.6	184.9	184.5	184.8
Gas	Mtoe	21.2	51.5	50.0	51.5	50.0
Other	Mtoe	31.4	89.4	88.1	88.8	87.6
Total	Mtoe	200.6	400.6	391.3	399.0	389.9
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	191.5	318.4	288.0	313.4	283.3
Petroleum	Mt CO_2e	287.9	524.2	525.6	524.3	525.6
Gas	Mt CO_2e	25.5	66.3	61.2	66.1	61.0
Total	Mt CO_2e	504.9	908.9	874.8	903.8	870.0
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	1.80	1.63	1.78	1.61
Petroleum	index	1.00	0.10	0.09	0.10	0.09
Gas	index	1.00	2.01	1.70	2.00	1.69
Total	index	1.00	1.61	1.43	1.59	1.41
Energy consumption in steel, by technology						
Blast furnace	index	1.00	1.70	1.45	1.59	1.36
Electric arc furnace	index	1.00	1.86	1.65	1.76	1.55
Total	index	1.00	1.73	1.48	1.62	1.39

continued

Malaysia

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	1.0	0.9	0.9	0.9	0.9
Black coal	Mtoe	1.1	14.0	12.5	12.9	11.4
Petroleum	Mtoe	25.3	76.9	77.0	76.9	77.1
Gas	Mtoe	21.4	62.0	50.1	57.5	47.5
Other	Mtoe	0.5	2.0	2.0	2.0	2.0
Total	Mtoe	49.3	155.9	142.5	150.3	138.9
Greenhouse gas emissions						
Brown coal	Mt CO_2e	3.4	3.1	3.1	3.1	3.1
Black coal	Mt CO_2e	3.9	10.8	11.0	10.9	11.0
Petroleum	Mt CO_2e	67.3	187.1	187.3	187.0	187.3
Gas	Mt CO_2e	50.0	126.7	103.8	118.7	99.1
Total	Mt CO_2e	124.5	327.7	305.1	319.7	300.5
Energy consumption in electricity, by fuel						
Brown coal	index	1.00	0.92	0.92	0.92	0.92
Steaming coal	index	1.00	16.92	14.91	15.43	13.45
Petroleum	index	1.00	0.06	0.06	0.06	0.06
Gas	index	1.00	2.54	2.06	2.37	1.96
Total	index	1.00	2.09	1.70	1.95	1.62
Energy consumption in steel, by technology						
Blast furnace	index	–	–	–	–	–
Electric arc furnace	index	1.00	2.66	2.09	2.48	1.95
Total	index	1.00	2.66	2.09	2.48	1.95

continued

Mexico

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	4.3	4.4	4.0	4.3	4.0
Black coal	Mtoe	3.3	3.9	3.6	3.8	3.6
Petroleum	Mtoe	93.7	193.2	192.7	193.0	192.6
Gas	Mtoe	38.5	128.7	106.4	123.4	102.9
Other	Mtoe	9.4	14.5	14.2	14.4	14.2
Total	Mtoe	149.2	344.6	321.0	338.9	317.3
Greenhouse gas emissions						
Brown coal	Mt CO_2e	22.0	22.3	20.5	22.1	20.4
Black coal	Mt CO_2e	9.7	14.3	12.0	13.8	11.6
Petroleum	Mt CO_2e	253.8	510.1	508.7	509.7	508.5
Gas	Mt CO_2e	105.5	347.6	284.9	332.9	274.9
Total	Mt CO_2e	391.0	894.3	826.1	878.6	815.4
Energy consumption in electricity, by fuel						
Brown coal	index	1.00	1.02	0.93	1.01	0.93
Steaming coal	index	1.00	2.13	2.10	2.12	2.09
Petroleum	index	1.00	0.68	0.67	0.68	0.67
Gas	index	1.00	3.62	2.90	3.45	2.79
Total	index	1.00	1.85	1.56	1.78	1.51
Energy consumption in steel, by technology						
Blast furnace	index	1.00	1.41	1.15	1.35	1.11
Electric arc furnace	index	1.00	2.47	2.05	2.34	1.95
Total	index	1.00	1.81	1.49	1.73	1.42

continued

New Zealand

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.1	0.1	0.1	0.1	0.1
Black coal	Mtoe	1.2	1.6	1.5	1.5	1.4
Petroleum	Mtoe	6.3	9.7	9.7	9.7	9.7
Gas	Mtoe	5.1	5.9	5.7	5.8	5.7
Other	Mtoe	4.2	7.1	7.0	7.1	7.0
Total	Mtoe	16.8	24.4	24.0	24.4	24.0
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.4	0.6	0.6	0.6	0.6
Black coal	Mt CO_2e	5.8	7.0	6.5	6.9	6.5
Petroleum	Mt CO_2e	16.1	23.9	23.9	23.9	23.9
Gas	Mt CO_2e	9.6	8.8	8.3	8.8	8.3
Total	Mt CO_2e	31.9	40.3	39.4	40.2	39.4
Energy consumption in electricity, by fuel						
Brown coal	index	1.00	1.52	1.50	1.52	1.49
Steaming coal	index	1.00	1.21	1.11	1.19	1.09
Petroleum	index	1.00	1.41	1.22	1.39	1.20
Gas	index	1.00	1.02	0.93	1.01	0.93
Total	index	1.00	1.05	0.96	1.04	0.95
Energy consumption in steel, by technology						
Blast furnace	index	1.00	0.97	0.83	0.95	0.81
Electric arc furnace	index	1.00	1.82	1.61	1.81	1.62
Total	index	1.00	1.04	0.89	1.02	0.88

continued

Peru

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	0.6	2.0	1.8	1.9	1.7
Petroleum	Mtoe	6.9	20.1	19.9	20.1	19.9
Gas	Mtoe	0.5	4.6	3.6	4.4	3.5
Other	Mtoe	1.7	3.2	3.1	3.2	3.1
Total	Mtoe	9.7	29.9	28.4	29.5	28.1
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	1.7	4.2	4.1	4.2	4.0
Petroleum	Mt CO_2e	24.0	48.3	47.7	48.2	47.5
Gas	Mt CO_2e	2.2	23.8	18.4	22.5	17.5
Total	Mt CO_2e	27.9	76.4	70.2	74.8	69.1
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	3.59	3.11	3.32	2.86
Petroleum	index	1.00	1.79	1.48	1.73	1.43
Gas	index	1.00	10.91	8.45	10.28	8.02
Total	index	1.00	4.63	3.70	4.37	3.51
Energy consumption in steel, by technology						
Blast furnace	index	1.00	1.42	1.18	1.37	1.09
Electric arc furnace	index	1.00	2.56	2.22	2.44	2.08
Total	index	1.00	1.78	1.51	1.71	1.40

continued

Philippines

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	4.9	11.9	11.4	11.5	10.9
Petroleum	Mtoe	16.2	31.1	30.3	31.0	30.2
Gas	Mtoe	1.4	4.8	4.0	4.6	3.8
Other	Mtoe	9.4	11.7	11.6	11.7	11.6
Total	Mtoe	32.0	59.4	57.2	58.7	56.5
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	22.4	53.0	50.2	50.9	48.0
Petroleum	Mt CO_2e	51.3	100.6	100.4	100.6	100.4
Gas	Mt CO_2e	7.0	23.4	19.4	22.6	18.8
Total	Mt CO_2e	80.8	176.9	170.0	174.1	167.2
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	2.02	1.82	1.88	1.68
Petroleum	index	1.00	0.62	0.61	0.62	0.61
Gas	index	1.00	3.35	2.78	3.24	2.69
Total	index	1.00	1.97	1.74	1.87	1.64
Energy consumption in steel, by technology						
Blast furnace	index	–	–	–	–	–
Electric arc furnace	index	1.00	2.58	1.98	2.36	1.80
Total	index	1.00	2.58	1.98	2.36	1.80

continued

Russian Federation

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	28.5	25.7	24.4	25.3	24.1
Black coal	Mtoe	78.3	95.6	89.9	91.9	85.8
Petroleum	Mtoe	128.4	240.8	242.2	240.9	242.3
Gas	Mtoe	325.6	552.5	531.2	542.8	526.5
Other	Mtoe	50.2	68.7	68.6	68.7	68.6
Total	Mtoe	610.9	983.3	956.2	969.7	947.2
Greenhouse gas emissions						
Brown coal	Mt CO_2e	99.7	86.4	81.4	85.0	80.2
Black coal	Mt CO_2e	324.2	394.3	365.9	375.9	346.5
Petroleum	Mt CO_2e	330.8	574.5	574.0	574.3	574.0
Gas	Mt CO_2e	624.1	944.3	901.2	919.2	889.5
Total	Mt CO_2e	1 378.8	1 999.5	1 922.5	1 954.4	1 890.2
Energy consumption in electricity, by fuel						
Brown coal	index	1.00	0.75	0.68	0.73	0.67
Steaming coal	index	1.00	1.21	1.10	1.14	1.02
Petroleum	index	1.00	0.68	0.68	0.68	0.68
Gas	index	1.00	1.00	0.76	0.87	0.70
Total	index	1.00	0.99	0.81	0.89	0.76
Energy consumption in steel, by technology						
Blast furnace	index	1.00	0.87	0.79	0.88	0.79
Electric arc furnace	index	1.00	1.16	1.05	1.18	1.07
Total	index	1.00	0.88	0.80	0.89	0.80

continued

Singapore

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Petroleum	Mtoe	21.5	37.3	37.3	37.3	37.3
Gas	Mtoe	3.7	11.4	9.6	11.2	9.3
Other	Mtoe	0.1	0.4	0.4	0.4	0.4
Total	Mtoe	25.3	49.1	47.3	48.9	47.0
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Petroleum	Mt CO_2e	35.2	60.8	60.7	60.8	60.8
Gas	Mt CO_2e	8.4	25.8	21.7	25.3	21.2
Total	Mt CO_2e	43.6	86.6	82.4	86.1	81.9
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	–	–	–	–	–
Petroleum	index	1.00	0.80	0.80	0.80	0.80
Gas	index	1.00	3.07	2.58	3.01	2.52
Total	index	1.00	2.03	1.76	2.00	1.73
Energy consumption in steel, by technology						
Blast furnace	index	–	–	–	–	–
Electric arc furnace	index	1.00	1.64	1.14	1.49	1.04
Total	index	1.00	1.64	1.14	1.49	1.04

continued

Chinese Taipei

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	33.3	61.1	55.7	60.0	54.4
Petroleum	Mtoe	42.5	71.3	71.4	71.3	71.4
Gas	Mtoe	6.9	28.2	24.2	27.7	23.9
Other	Mtoe	10.9	5.6	5.6	5.6	5.6
Total	Mtoe	93.6	166.2	156.9	164.6	155.3
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	114.3	209.1	190.6	205.4	186.2
Petroleum	Mt CO_2e	94.6	163.7	163.9	163.6	163.8
Gas	Mt CO_2e	14.7	62.4	51.2	61.0	50.5
Total	Mt CO_2e	223.6	435.2	405.7	430.0	400.5
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	1.98	1.80	1.95	1.75
Petroleum	index	1.00	0.66	0.65	0.66	0.65
Gas	index	1.00	4.82	3.91	4.71	3.84
Total	index	1.00	2.22	1.95	2.17	1.91
Energy consumption in steel, by technology						
Blast furnace	index	1.00	1.12	0.92	1.07	0.88
Electric arc furnace	index	1.00	1.08	0.92	1.04	0.88
Total	index	1.00	1.11	0.92	1.06	0.88

continued

Thailand

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	5.7	5.4	5.4	5.4	5.4
Black coal	Mtoe	3.3	25.9	24.3	24.7	23.1
Petroleum	Mtoe	37.9	113.7	113.4	113.7	113.4
Gas	Mtoe	21.9	68.7	57.4	66.6	55.7
Other	Mtoe	0.9	4.3	4.3	4.3	4.3
Total	Mtoe	69.6	218.0	204.7	214.8	201.9
Greenhouse gas emissions						
Brown coal	Mt CO_2e	29.6	45.0	44.9	45.0	45.0
Black coal	Mt CO_2e	11.6	121.0	111.1	113.7	104.0
Petroleum	Mt CO_2e	99.2	302.1	301.4	302.1	301.7
Gas	Mt CO_2e	49.4	170.6	142.0	165.5	137.8
Total	Mt CO_2e	189.8	638.7	599.5	626.4	588.4
Energy consumption in electricity, by fuel						
Brown coal	index	1.00	0.45	0.44	0.45	0.44
Steaming coal	index	1.00	45.12	39.67	41.14	35.76
Petroleum	index	1.00	0.24	0.24	0.24	0.24
Gas	index	1.00	3.50	2.90	3.39	2.81
Total	index	1.00	3.43	2.89	3.29	2.76
Energy consumption in steel, by technology						
Blast furnace	index	–	–	–	–	–
Electric arc furnace	index	1.00	2.88	2.39	2.72	2.25
Total	index	1.00	2.88	2.39	2.72	2.25

continued

United States

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	25.0	27.7	25.3	27.3	24.9
Black coal	Mtoe	517.0	742.0	680.7	729.2	667.7
Petroleum	Mtoe	900.1	1 405.9	1 407.3	1 406.0	1 407.5
Gas	Mtoe	537.2	781.1	740.6	775.1	737.1
Other	Mtoe	242.2	275.5	274.6	275.3	274.5
Total	Mtoe	2 221.5	3 232.2	3 128.5	3 212.8	3 111.7
Greenhouse gas emissions						
Brown coal	Mt CO_2e	274.7	303.6	277.4	298.8	273.2
Black coal	Mt CO_2e	1 849.8	2 676.0	2 460.3	2 634.0	2 416.3
Petroleum	Mt CO_2e	2 431.9	3 314.3	3 312.8	3 314.5	3 313.1
Gas	Mt CO_2e	1 131.7	1 619.1	1 481.2	1 597.8	1 468.7
Total	Mt CO_2e	5 688.1	7 912.9	7 531.7	7 845.1	7 471.3
Energy consumption in electricity, by fuel						
Brown coal	index	1.00	1.09	0.99	1.07	0.97
Steaming coal	index	1.00	1.46	1.34	1.44	1.31
Petroleum	index	1.00	0.89	0.83	0.89	0.83
Gas	index	1.00	1.56	1.31	1.52	1.29
Total	index	1.00	1.45	1.30	1.42	1.28
Energy consumption in steel, by technology						
Blast furnace	index	1.00	1.10	0.90	1.06	0.87
Electric arc furnace	index	1.00	1.15	0.97	1.10	0.93
Total	index	1.00	1.11	0.92	1.07	0.88

continued

Viet Nam

		Reference case		HT	AA	HTAA
		2002	2030	2030	2030	2030
Total energy consumption						
Brown coal	Mtoe	0.0	0.0	0.0	0.0	0.0
Black coal	Mtoe	5.5	25.8	25.9	25.7	25.7
Petroleum	Mtoe	10.0	33.3	33.4	33.3	33.4
Gas	Mtoe	2.3	10.3	9.9	10.1	9.8
Other	Mtoe	1.6	7.9	7.9	7.9	7.9
Total	Mtoe	19.4	77.4	77.1	77.1	76.8
Greenhouse gas emissions						
Brown coal	Mt CO_2e	0.0	0.0	0.0	0.0	0.0
Black coal	Mt CO_2e	15.3	69.4	69.0	68.7	68.1
Petroleum	Mt CO_2e	23.1	77.4	77.6	77.4	77.7
Gas	Mt CO_2e	3.1	20.4	15.9	18.9	15.0
Total	Mt CO_2e	41.5	167.2	162.5	165.0	160.8
Energy consumption in electricity, by fuel						
Brown coal	index	–	–	–	–	–
Steaming coal	index	1.00	3.64	3.24	3.35	2.95
Petroleum	index	1.00	0.68	0.68	0.68	0.68
Gas	index	1.00	6.49	5.06	6.00	4.79
Total	index	1.00	4.20	3.43	3.89	3.22
Energy consumption in steel, by technology						
Blast furnace	index	–	–	–	–	–
Electric arc furnace	index	1.00	11.48	9.57	11.00	9.10
Total	index	1.00	11.48	9.57	11.00	9.10

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