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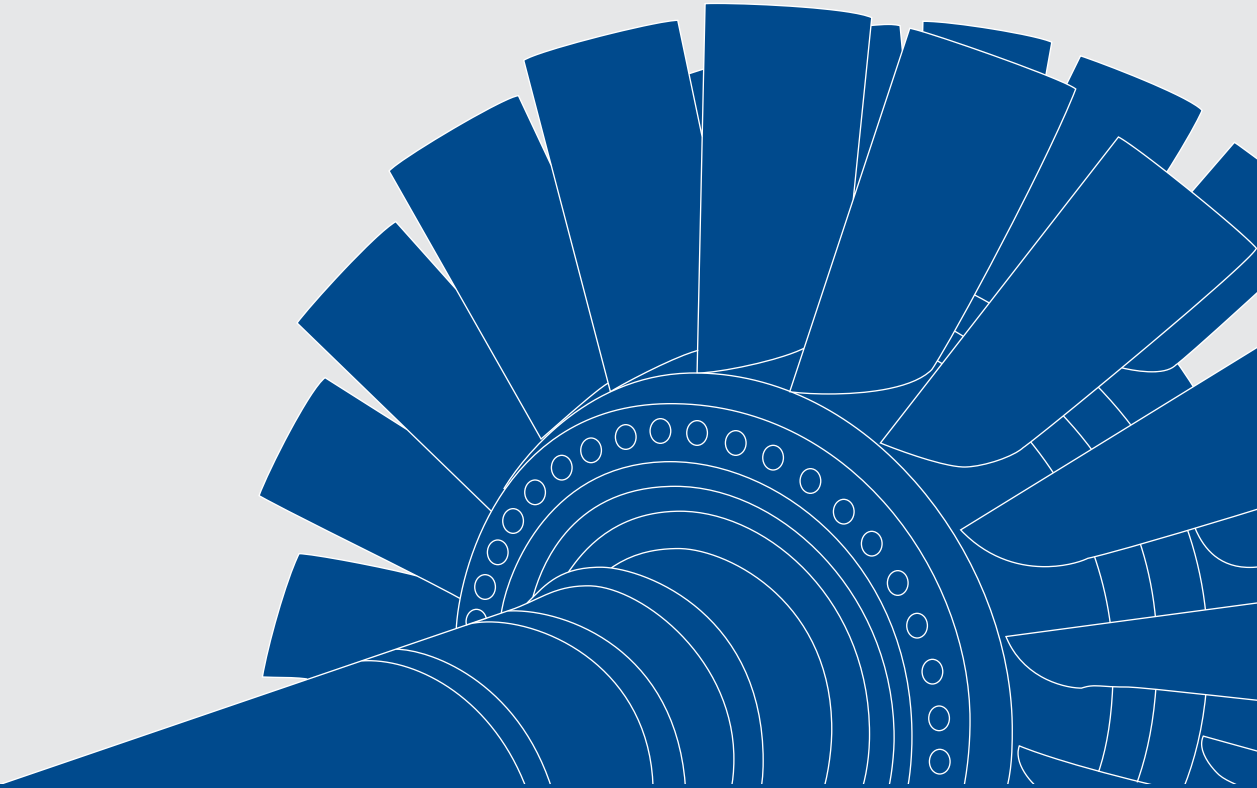
Energy Efficiency in the APEC Region

Electricity Sector



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ENERGY EFFICIENCY IN THE APEC REGION

THE POWER SECTOR

ASIA PACIFIC ENERGY RESEARCH CENTRE

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FOREWORD

We are pleased to present the report, *Energy Efficiency in the APEC Region – The Power Sector*.

Growing energy security and environmental concerns have recently encouraged most APEC economies to put energy efficiency at the top of their energy policy agenda. Energy efficiency policies and projects, however, have not been fully successful for various reasons. The objective of this study is to investigate some of the key issues likely to influence energy efficiency improvements in the power sector.

The report is published by APERC as an independent study and does not necessarily reflect the views or policies of the APEC Energy Working Group or individual member economies. Nevertheless, we do hope that it will serve as a useful basis for analytical discussion both within and among APEC member economies for the enhancement of energy security in APEC and sustainable development around the world.

Kobayashi

Kenji Kobayashi
President
Asia Pacific Energy Research Centre

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Energy efficiency in the power sector can be examined from a demand and/or supply perspective. In terms of a demand-side outlook, efficiency focuses on reducing sectoral electricity consumption. Supply-side energy efficiency refers to reducing the primary energy input required to produce each unit of electricity. Although demand-side efficiency measures can provide significant savings, this report focuses on supply-side issues.

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LIST OF ABBREVIATIONS

APEC	Asia Pacific Economic Cooperation
APERC	Asia Pacific Energy Research Centre
ASEAN	Association of Southeast Asian Nations
AUS	Australia
BCM	billion cubic metres
BD	Brunei Darussalam
CCGT	combined-cycle gas turbine
CDA	Canada
CDM	Clean Development Mechanism
CHL	Chile
CO_2	carbon dioxide
CT	Chinese Taipei
DSM	Demand Side Management
DOE	Department of Energy (USA)
EDMC	Energy Data and Modelling Center (Japan)
EIA	Energy Information Administration (USA)
EWG	Energy Working Group (APEC)
FBC	fluidised bed combustion
GDP	gross domestic product
GGAS	greenhouse gas abatement scheme
GHG	greenhouse gases
g/kWh	grams per kilowatt-hour (used to measure the emissions caused by the generation of one unit of electricity)
GW	gigawatt
GWh	gigawatt-hour
HKC	Hong Kong, China
IEA	International Energy Agency
IEEJ	Institute of Energy Economics, Japan
IGCC	integrated gasification combined-cycle
INA	Indonesia
IPCC	Intergovernmental Panel on Climate Change
JPN	Japan
kgoe	kilogram of oil equivalent
ktoe	thousand tonnes of oil equivalent

LNG	liquefied natural gas
LPG	liquefied petroleum gas
MAS	Malaysia
mbd	million barrels per day
MCM	million cubic metres
MEX	Mexico
MMBTU	Million British Thermal Units
Mtoe	million tonnes of oil equivalent
NRE	new and renewable energy
NGAC	New South Wales Greenhouse Abatement Certificates
NOx	unspecified nitrogen oxides
NO_2	nitrogen dioxide
NZ	New Zealand
O_3	(surface) ozone
PCC	pulverised coal combustion
PE	Peru
PM	particulate matter of unspecified diameter (generally <10 microns)
PNG	Papua New Guinea
PPM	parts per million
PPP	purchasing power parity
PRC	People's Republic of China
R&D	research and development
RDF	refused derived fuel
ROK	Republic of Korea
RP	the Republic of the Philippines
RUS	the Russian Federation
SIN	Singapore
SO_2	sulphur dioxide
toe	tonnes of oil equivalent
TWh	terawatt hours
UNFCCC	United Nations Framework Convention on Climate Change
US or USA	United States of America
USD	United States dollar
WTO	World Trade Organisation
VN	Viet Nam

GLOSSARY

TECHNOLOGY

Higher heating value (HHV)/gross heating value

The gross or HHV is the amount of heat produced by the complete combustion of a unit quantity of fuel. The gross heating value is obtained when all products of the combustion are cooled down to the temperature before the combustion and the water vapour formed during combustion is condensed.

Lower heating value (LHV)/Net calorific value

The net or LHV is obtained by subtracting the latent heat of vaporisation of the water vapour formed by the combustion of fuel from the gross or higher heating value.

OVERVIEW

Energy efficiency improvements in the power sector can greatly contribute to an enhancement in energy security and sustainable development. The power sector is the largest consumer of total primary energy in APEC (32 percent in 2005) and fossil fuel power generation accounts for more than 70 percent of APEC's generation mix. Thus, the power generation sector plays a key role in ensuring the region's energy security.

APEC's diversity in energy resource endowment, together with the technological trend of higher efficiencies in thermal power generation, provides different motivation for each economy to transform the sector. For some economies that want to reduce the initial financial burden, retrofitting or refurbishing of existing generation may be the most useful path. Other economies may prefer to adopt a substantial share of new *higher-efficiency* generation capacity since it can provide faster results for economies to improve energy efficiency.

From a utility's point of view, major priorities include an economy's power demand growth, availability of fuel resources, and domestic fuel prices. The choice of technology may be considered only after these parameters are satisfactorily met. Thus, technology adoption among APEC economies, in the past and into the future, varies accordingly.

To address the feasibility of enhancing energy efficiency in the power sector, this report tackles several of these issues from a supply-side perspective.

INSIGHT FROM THE PAST: HISTORICAL ENERGY EFFICIENCY TRENDS

Deployment of advanced power generation technologies, when building additional power generating capacity, can enhance efficiency levels. The advent of new technologies, specifically in coal and natural gas-fired power generation, makes higher energy efficiency targets more feasible today than they were 10 years ago. In the recent past, a 30 to 35 percent efficiency was considered satisfactory and ideal for a thermal power generating unit. Today, this number is considered dated in view of the proliferation of power generating units with efficiencies greater than 40 percent.

Understanding the historical context of energy efficiency improvement within each APEC economy and the region as a whole is essential to determine the potential to achieve future energy efficiency targets. Without a good understanding of each economy's status, future policies could prove inadequate and result in an unsustainable energy future.

In this chapter, an overview of power generation characteristics in APEC economies, focusing on generation trends and changes in generation mix, is presented.

The analysis examines the thermal efficiency trends, in APEC economies, of fossil fuel power generation. In addition, a decomposition analysis is used to determine the factors that influence the growth of primary energy demand for power generation from 1985 to 2005.

Highlights

- The cost of power generation (capital investment, O&M, and input fuel costs) is an important factor that influences the type of energy used for power generation.
- The two main drivers that affect the overall thermal efficiency improvement in an economy include (1) energy switching that corresponds with an adoption of efficient technologies and (2) changes in the operating conditions of power plants.
- The power sector's *primary energy demand* growth is largely attributed to an increase in power generation. Therefore, a strategy to (1) identify areas for energy efficiency improvement and (2) create conditions to realise potential energy savings in the power sector is necessary.

PERSPECTIVE OF THE FUTURE: A SCENARIO ANALYSIS

Power generation within each of the twenty-one economies of the APEC region is distinctive. This uniqueness stems from each economy's energy resource endowment, degree of generation mix diversification (in terms of number and respective share of energy-types), and the technology used to convert this primary energy into electricity. Thus, there are several means to achieve energy efficiency improvements in the power sector.

This chapter aims to forecast the potential for APEC economies to capitalise on technological trends of higher efficiencies in thermal power generation to achieve targets of greater energy savings and emissions reduction.

Through developing a hypothetical case of a 10 to 15 percent thermal efficiency improvement in the power sector, from 2005 to 2030, this chapter calculates potential energy and CO_2 emissions reduction savings within APEC economies. In addition, an index is created to further understand the likelihood that an economy will invest in energy efficiency improvements. This index is designed to capture the importance of risk factors that can encourage an economy to improve the efficiency of its power sector.

Highlights

- Compared to a 10 to 15 percent energy efficiency improvement in natural gas-fired generation, an improvement in coal-fired power generation can produce approximately 2x the energy and 4x the CO_2 emissions reduction savings.
- Historical energy efficiency improvements and future improvement potential are different. Some economies may have already exhausted the efficiency improvement options that are low effort. However, attractive low effort options may still be available for developing economies.
- An economy's likelihood to improve coal-fired power generation efficiency mainly depends on its existing generation capacity age structure. In contrast, for natural gas-fired generation, an economy with a higher per capita natural gas import dependency has a higher likelihood (or need) to improve its power generation efficiency.

THE GRADUAL APPROACH: RETROFITTING AND REFURBISHING

Thermal power plant efficiency deteriorates with time. As such, utilities need to continuously take action to regain and increase efficiency, where technically possible. The rate of this efficiency decline differs by power plant due to specifics in plant design and incorporated features, and most importantly on how well the plant is maintained.

Power plant retrofits and refurbish measures, as they become necessary, are imperative to regain a plant's design condition efficiency and to optimise plant conversion efficiency. The economic benefit of plant retrofits and refurbish measures can be significant in terms of energy and CO_2 emissions reduction savings.

The objective of this chapter is to assess the potential energy savings and avoided carbon emissions (of existing power plants) that can be attainted by increasing power plant efficiency through retrofitting and refurbishing.

The analysis is limited to coal-fired power plants because they constitute a significant share of total power generation capacity in the APEC region and have a higher efficiency improvement potential, among fossil fuelled power plants.

Highlights

- The average economic life of a power plant is 30 years. Approximately three fourths of the installed coal-fired power generation in the region is at least 20 years old. These older power plants offer great potential for energy savings.
- Better plant maintenance and operation is vital for retrofit measures to generate any efficiency improvement.
- Timely investment to refurbish plant components, in conjunction with retrofit measures that incorporate technological advancements and the implementation of best practices in maintenance and operation, may actually offset the plant aging process and extend the life of a plant.

THE LEAPFROGGING APPROACH: TECHNOLOGICAL ROADMAP

Prospects for a potential technology future entail the development of more efficient, less polluting, and more cost competitive technology for both coal and natural gas-fired power generation. This can be achieved through further refinement and/or innovative hybridisation of existing technologies.

To understand the potential and possible areas for energy efficiency improvement, this chapter presents historical trends for the power generation technologies that have been applied in APEC.

The discussion in this chapter is concentrated on fossil fuel power generation technologies, mainly on coal-fired power generation and natural gas-fired power generation technologies. It tries to characterise available technologies, including both conventional and advanced, on such aspects as thermal efficiencies, emissions, and capital investment requirements. The chapter also offers a possible future roadmap for the deployment of power generation technologies.

Highlights

- The deployment of advanced technology is not directly related to an economy’s economic development level.
- Capital investment is the defining factor that determines the penetration of technology into the market. As such, it is important that R&D for next-generation technologies also advance innovations that can help reduce cost and be used with existing technologies. This may help best practice technologies gain greater market penetration.
- Technology transfer from developed to developing economies can help towards the diffusion of advanced technologies. To realise such a win-win situation for both host economy and investors, policymakers in developing economies should create suitable conditions that can facilitate investment by foreign manufactures.

ENERGY EFFICIENCY INVESTMENT IN THE POWER SECTOR: BARRIERS AND FACILITATORS

Adoption of energy efficient power technologies, through refurbishment or total replacement, can bring substantial benefits to generators, as well as to society as a whole. Generators can reduce their energy procurement costs and potential emission fees (related to both local and global emissions reduction). Society may also directly enjoy benefits, such as air quality improvement, as a result of the introduction of energy efficient power generation technologies.

Despite these benefits, generators often choose less energy efficient technologies, due mainly to lower initial capital requirements. Under a deregulated market, in particular, power generators may place priority on how to supply electricity at a competitive retail price.

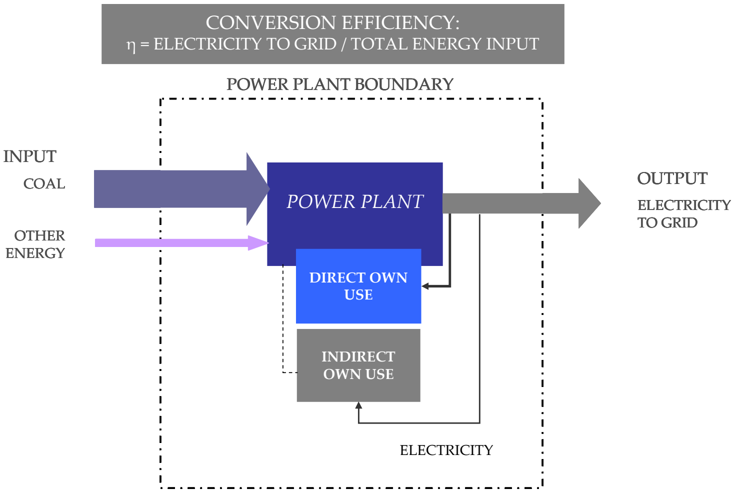
This chapter explores barriers to the adoption of energy efficient power generation technologies. The analysis begins with a brief overview of investment barriers. This assessment is followed by a few cases of policies and measures that can help facilitate investment in energy efficient technologies.

Highlights

- Regulation, on energy efficiency or the environment, and financial incentives are equally necessary to promote the wider adoption of energy efficient generation technologies.
- For developing economies, CDM could play a critical role towards the wider application of energy efficient power generation technologies. A mechanism should be created to balance the needs of host economies with that of investing economies, through bilateral or multilateral agreements among governments.
- Solely supply-side focused energy efficiency improvement measures, such as tax breaks and lower interest rates, may increase electricity generation (at a lower cost), thus, increasing overall energy consumption. To fully realise energy efficiency improvement potential, demand-side measures should be integrated with supply-side measures.

DEFINING A GIANT: ENERGY EFFICIENCY

Energy conversion efficiency or energy efficiency for short is a measure of the effectiveness and efficacy of an energy conversion technology, i.e. a power plant, in converting primary energy into electric power. It is defined as the ratio between useful output (electricity) of an energy conversion technology and input, in common energy units [7.1]. This definition of energy efficiency applies for all energy conversion technologies.



7.1 **Power flow diagram for coal-fired power generation**

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The formula for determining energy efficiency, which is usually applied to fossil fuel based conversion technologies (where input and output are readily known), can also be applied to other conversion technologies, such as wind, tidal, and solar power generation, as well as nuclear and fuel cells.[a]

Energy efficiency is a means to measure the conversion of primary energy into electricity. The term energy efficiency is often misused to describe

(1) the effectiveness of final energy use, in terms of electricity and heat, in co-generation or

(2) primary energy savings from the restraint of use.

The above examples are not energy conversion efficiencies.[b] The first refers to a plant's fuel utilisation rate, while the second refers to energy conservation. Although the term energy efficiency is often used loosely to suggest all of the above, this report will solely focus on energy conversion efficiency.

Generally, energy efficiency is determined by generation technology, however, there are a number of indirect measures to increase or sustain

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[a] *Aart et al. 2004*

[b] *Aart et al. 2004*

energy conversion efficiency. These measures include: increasing or sustaining the heat rate, improving the capacity factor by means of better plant management and system operation, demand-side management (DSM) measures, and by retrofitting or re-powering power plants (often through incorporating the latest technology). Additionally, reducing operational own use is often considered a means to increase energy efficiency, since own use is considered an integral component of the conversion process.

INSIGHT FROM THE PAST:
HISTORICAL ENERGY EFFICIENCY TRENDS

INTRODUCTION

Energy efficiency in the power sector can be examined from a demand and/or supply perspective. In terms of a demand-side outlook, efficiency focuses on reducing electricity consumption in the industrial, commercial, and residential sectors. Although demand side efficiency measures can provide significant savings, the focus of this analysis will centre on supply-side issues.

Supply-side energy efficiency refers to the utilisation of primary energy for producing each unit of electricity. The demand for primary energy is affected by electricity generation growth, generation mix changes, and the thermal efficiency of fossil fuel power generation. System losses, a combination of plant own use and transmission and distribution (T&D) losses, also impact primary energy requirements.

Power plant *own use* losses:

- The share of electricity that a plant uses for its own generation and operation.

Transmission and distribution (T&D) losses:

- The share of electricity losses between sources of supply (generating stations), points of distribution, and ultimate end-users. These losses occur through the transmission and distribution network.

9.1 **Definitions: Plant own use and T&D losses**

In this chapter, an overview of power generation characteristics in APEC economies, focusing on generation trends and changes in generation mix, is presented.

The analysis examines the thermal efficiency trends, in APEC economies, of fossil fuel power generation. The thermal efficiency trends of coal-fired, natural gas-fired, and oil-fired power generation are examined separately.

In addition, a decomposition analysis is used to identify the factors that influence the growth of primary energy demand for power generation from 1985 to 2005. The factors analysed include total electricity generation, generation mix, and energy efficiency. Changes in each factor are examined separately.[a]

AN OVERVIEW OF POWER GENERATION IN APEC

From 1990 to 2005, power generation in the APEC region increased at 3.2 percent per year, while GDP grew at 3.8 percent.[b] Due to differences in economic development levels, industry structures, and efficiency improvements, the growth trends of power generation vary substantially in APEC economies. This continuum ranges from a high growth rate of 12.9 percent per year (Viet Nam) to a low of – 0.9 percent per year (Russia).

In APEC, four economies account for more than 80 percent of the incremental growth of power generation from 1990 to 2005. These economies include: China (44.1 percent), the United States (25.1 percent), Korea (6.6 percent), and Japan (6.1 percent).

In terms of energy-type, coal-fired power generation shows the highest rate of incremental growth, 97 percent, from 2,732 TWh (1990) to 5,371 TWh (2005). Natural gas-fired power generation increased by 74 percent, from 1,145 TWh to 1,995 TWh, over the same period. Oil-fired power generation, however, decreased by 24 percent to 580 TWh in 2005.

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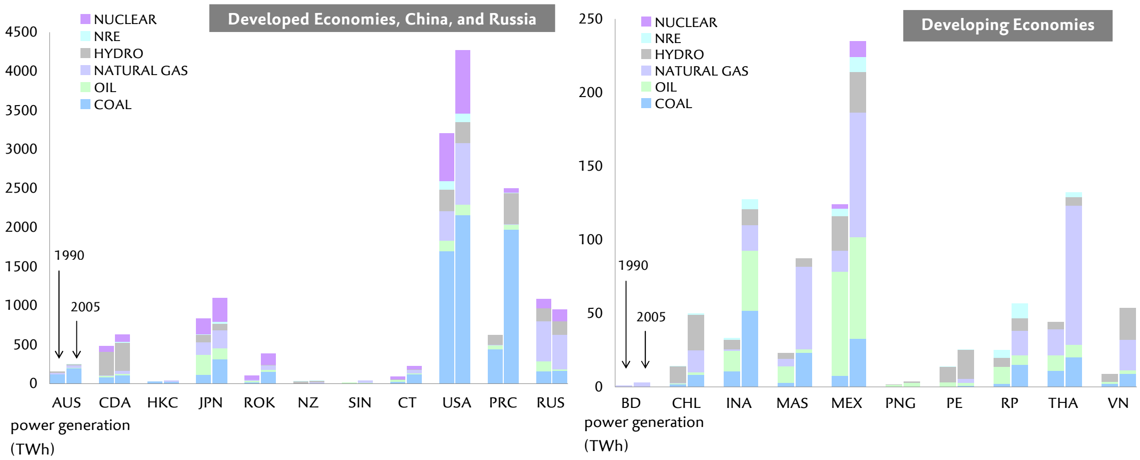
[a] *The methodology used for the decomposition analysis and the calculations for energy efficiency and system losses are given in Appendix I.*

[b] *To calculate the growth rate of APEC's power generation, 1990 is used as the base year because Russia's data is only available from 1990 onwards.*

In terms of non-fossil fuel power generation, power generation in nuclear, hydro, and other NRE increased by 47 percent, 36 percent, and 37 percent to respectively reach 1,608 TWh, 1,460 TWh, and 189 TWh in 2005.



10.1 **Power generation in APEC, by economy and energy (1990 and 2005)**

Due to limited data availability in Papua New Guinea, the share of oil in total energy includes natural gas.
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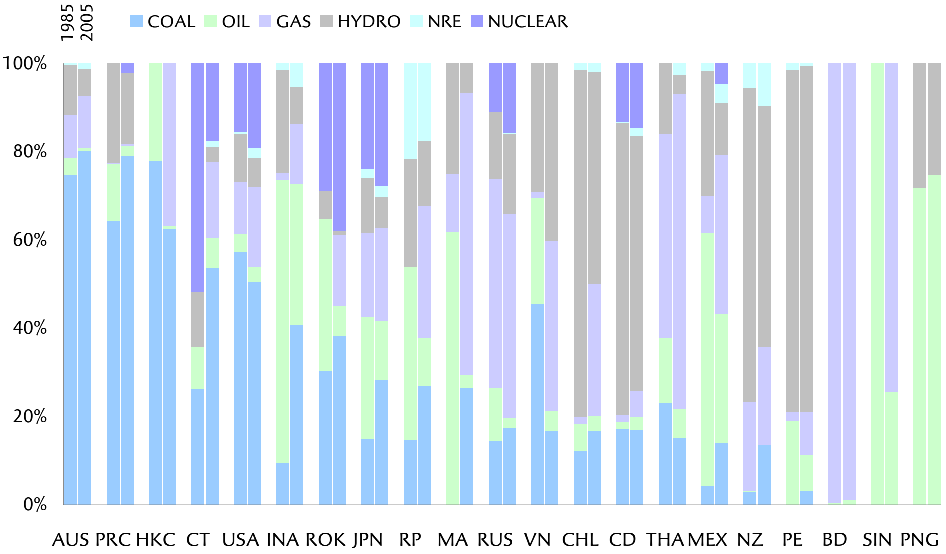
ENERGY DIVERSIFICATION AND GENERATION MIX CHANGES

After the first and second oil crises, APEC economies took various measures to diversify their energy mix in order to reduce oil dependence. In the electricity sector, oil was generally replaced by natural gas, nuclear, and coal, depending on the energy resource endowment and energy policies within each APEC economy [10.2].



10.2 **Power generation mix by energy-type (1985 and 2005)**

Due to limited data availability in Papua New Guinea, the share of oil in total energy includes natural gas.
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From 1985 to 2005, Indonesia and Malaysia replaced oil with indigenously produced coal and natural gas for power generation. Recently, Indonesia implemented a 10,000 MW coal power generation crash programme to switch away from oil in power generation.[c]

Japan and Korea, two net energy importers, increased their reliance on natural gas, nuclear, and most recently on coal to reduce oil demand and increase their power generation sectors' energy diversification. Similarly, Hong Kong, with almost 100 percent energy import dependence, reduced its share of oil in power generation from 22 percent in 1985 to 1 percent in 2005. Oil was first replaced by coal and then, after 1996, by natural gas. The Philippines also introduced natural gas to replace oil in order to reduce oil import dependence and increase the degree of energy diversification in power generation. This shift was promoted even though natural gas imports were required to meet demand growth.[d]

Although the most obvious, oil is not the only energy source that has been replaced by others in power generation. Energy switching has also occurred from coal to natural gas, hydro to coal and/or natural gas, and nuclear to fossil fuels.

Switching from coal to natural gas occurred in Thailand, Viet Nam, and the United States. In Viet Nam, the share of natural gas-fired power generation in the generation mix increased from 1 percent in 1985 to 39 percent in 2005, while the share of coal-fired power generation decreased from 45 percent to 17 percent over the same period. In the United States, the installed capacity of coal-fired power generation increased slowly from 303 GW in 1989 to 313 GW in 2005 (0.2 percent per year), while the installed capacity of natural gas-fired power generation grew more robustly from 166 GW to 383 GW (5 percent per year). The growth in natural gas-fired power generation was due to an increase in the popularity of combined-cycle gas turbines (CCGT), which have a lower capital investment requirement and relatively short construction lead time compared with coal-fired power generation and nuclear.

Nevertheless, coal still remains the dominant energy source for power generation in the APEC region. It accounts for the largest share in total power generation, at 48 percent (2005), 30 percentage points higher than natural gas, which has the second largest share. With abundant coal resources among APEC economies, coal is the favourable option for energy security in power generation. The relatively cheap price of coal is another factor that supports its sheer dominance, relative to oil and natural gas, in total power generation.

In terms of hydro power generation, data reveals a decline in its contribution to the total generation mix in the region. As of 2005, eighteen APEC economies rely on hydro for power generation.[e] Only three of these economies (Peru, Russia, and Viet Nam) increased the share of hydro power generation from 1985 to 2005. The remaining fifteen economies showed a decreasing trend in terms of the share of hydro over the same period. Chile, for example, diversified its power generation mix by decreasing hydro and increasing natural gas-fired and coal-fired power generation.

NRE (solar, wind, biomass, and geothermal) are alternative options to reduce fossil fuel use in power generation. In 2005, the Philippines had the world's second largest geothermal power generating capacity at 1.9 GW, generating about 9,902 GWh (equivalent to 851 ktoe). Similar to the Philippines, Indonesia also has a significant geothermal potential for power generation, estimated at 27,000 MW. Nevertheless, geothermal currently only accounts for 3 percent (855.5MW) of Indonesia's total installed power generation capacity. In New Zealand, geothermal is one of the main renewable energy sources and wind power has gained momentum in recent years.

Development of wind for power generation, as well as solar, has also been promoted. The Chinese government, for example, plans to increase the total installed capacity of wind and solar power to 30GW and 1.8GW by 2030.

Nevertheless, NRE's contribution to total power generation within APEC remains at only 2 percent (2005), a 1 percent increase from 1985. This is due mainly to NRE's high capital cost.

11.1 NRE: Potential vs. reality

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[c] *APERC 2007*

[d] *Department of Energy, Republic of the Philippines 2005*

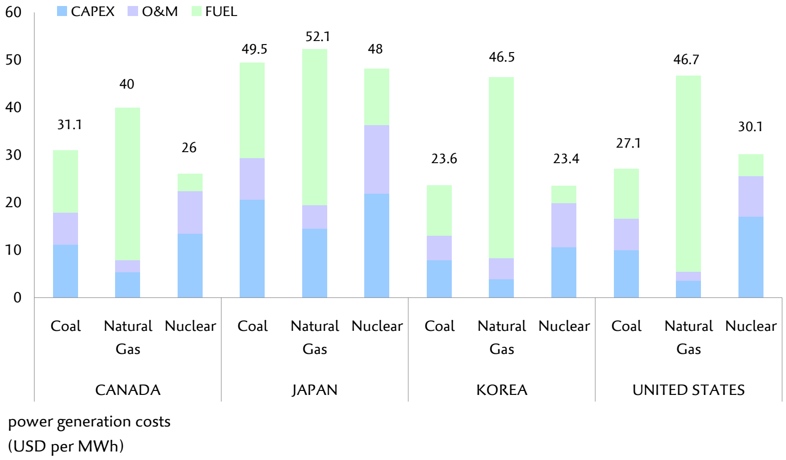
[e] *Excludes Brunei Darussalam, Hong Kong, and Singapore.*

POWER GENERATION COSTS

The cost of power generation (capital investment, O&M, and input fuel costs) is an important factor that influences the type of energy used for power generation. In [12.1], the power generation costs for coal-fired, natural gas-fired, and nuclear power generation are presented for Canada, Japan, Korea, and the United States.

It is important to note that [12.1] should only be used to grasp a general picture of power generation costs and to compare generation costs by energy-type. Direct cost comparison among economies is not appropriate. Capital costs for a technology can vary depending on technology availability, land prices, interest rates, and safety requirements, while O&M costs can differ depending on the cost of labour and a plant's age and scale. Additionally, input fuel costs will vary based on an economy's resource endowment and energy transport infrastructure availability.

Data reveals that nuclear is competitive, in terms of generation cost per MWh, in Canada, Japan, and Korea. This is mainly due to low input fuel costs. In contrast, coal-fired power generation is competitive in the United States, since the economy relies mainly on domestically produced coal, which is less expensive. Due to its higher input fuel cost, natural gas-fired power generation represents the highest generation cost per MWh although its capital cost is the lowest among the three generation types.



12.1 **Power generation costs (nominal USD per MWh)**

The generation cost calculations assume an 85 percent utilisation ratio and a 5 percent discount rate. The calculations for coal-fired and nuclear power generation assume an economic lifetime of 40 years, while the calculations for natural gas-fired power generation assume a lifetime between 20 and 30 years.

IEA and NEA 2005

In APEC, as a whole, nuclear's contribution to total power generation remained the same, at 14 percent, from 1985 to 2005. However, its status varies greatly among the eight APEC economies that have nuclear power generation.[f] In Chinese Taipei, for example, the construction of new nuclear power plants is prohibited due to the Nuclear-Free Homeland policy that was announced in 2001. As a result, nuclear's share in total power generation decreased from 52 percent (1985) to 18 percent (2005).

In contrast, Korea's nuclear share has increased, from 29 percent (1985) to 38 percent (2005), as the economy tries to diversify its generation mix to reduce oil dependence in the power sector. China has

[f] *These economies include Canada, China, Japan, Korea, Mexico, Russia, Chinese Taipei, and the United States.*

also increased its use of nuclear power generation, from zero (1985) to 8 power plant units (2005). As of 2005, nuclear power generation accounts for 2 percent of China's generation mix.

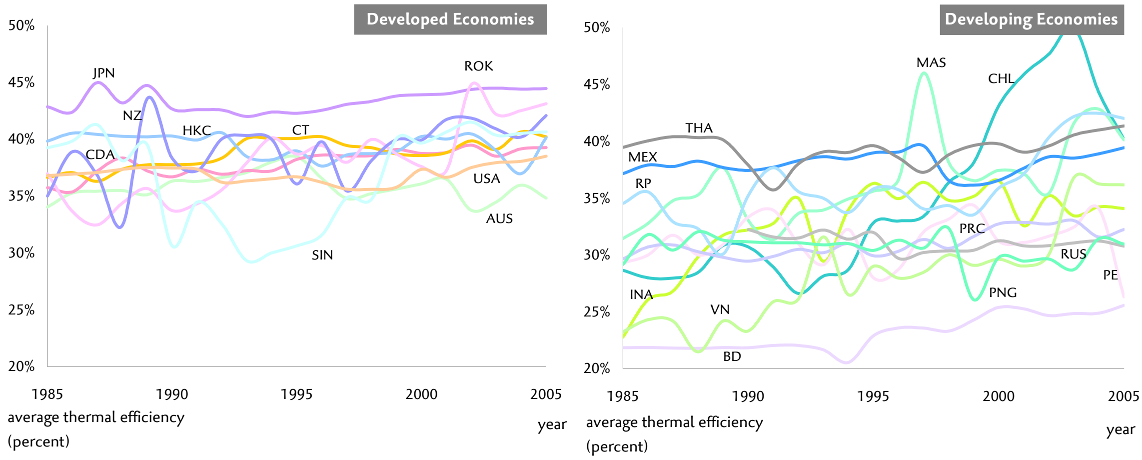
THERMAL EFFICIENCY TRENDS OF FOSSIL FUEL POWER GENERATION

Power generation energy efficiency can be split up into (1) fossil fuel based and (2) non-fossil fuel based conversion efficiency. Energy efficiency in fossil fuel power generation is often referred to as thermal efficiency. In non-fossil fuel based power generation (nuclear, hydro, and other NRE), energy efficiency is solely referred to as conversion efficiency.

The overall average thermal efficiency of fossil fuel power generation in APEC economies has improved over the past two decades [13.1].[8] In 2005, the average thermal efficiency for fossil fuel power generation in the APEC region, weighted by the amount of generation, was 36 percent, compared with 35 percent in 1985.

However, the thermal efficiency of fossil fuel power generation in APEC varies widely. Among developed economies, it ranges from 35 percent (Australia) to 44 percent (Japan). In developing economies, wider disparity is observed, ranging from 26 percent (Brunei Darussalam) to 42 percent (Philippines).

It is important to note that in 2005 the average thermal efficiency in six developing economies (the Philippines, Thailand, Chile, Malaysia, Mexico, and Viet Nam) was within the thermal efficiency range of developed economies in the same year. This may suggest that factors other than an economy's economic development level can affect the overall thermal efficiency of fossil fuel power generation.



13.1 **Average thermal efficiency of fossil fuel power generation in APEC (1985 to 2005)**

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[8] *For simplicity purposes, APEC economies are classified into two groups: 1) developed and 2) developing economies. In this section, figures showing the thermal efficiency trends of power generation are separated accordingly.*

An economy's power generation thermal efficiency is calculated by dividing its electricity generation by the energy input required to produce that electricity. Since certain economies have power plants with combined heat and power (CHP) units (Canada, Korea, Russia, and the United States), a different methodology is applied in these cases to calculate the thermal efficiency of power generation. Detailed calculations are provided in Appendix I.

FACTORS AFFECTING AN ECONOMY'S AVERAGE THERMAL EFFICIENCY

GENERATION MIX

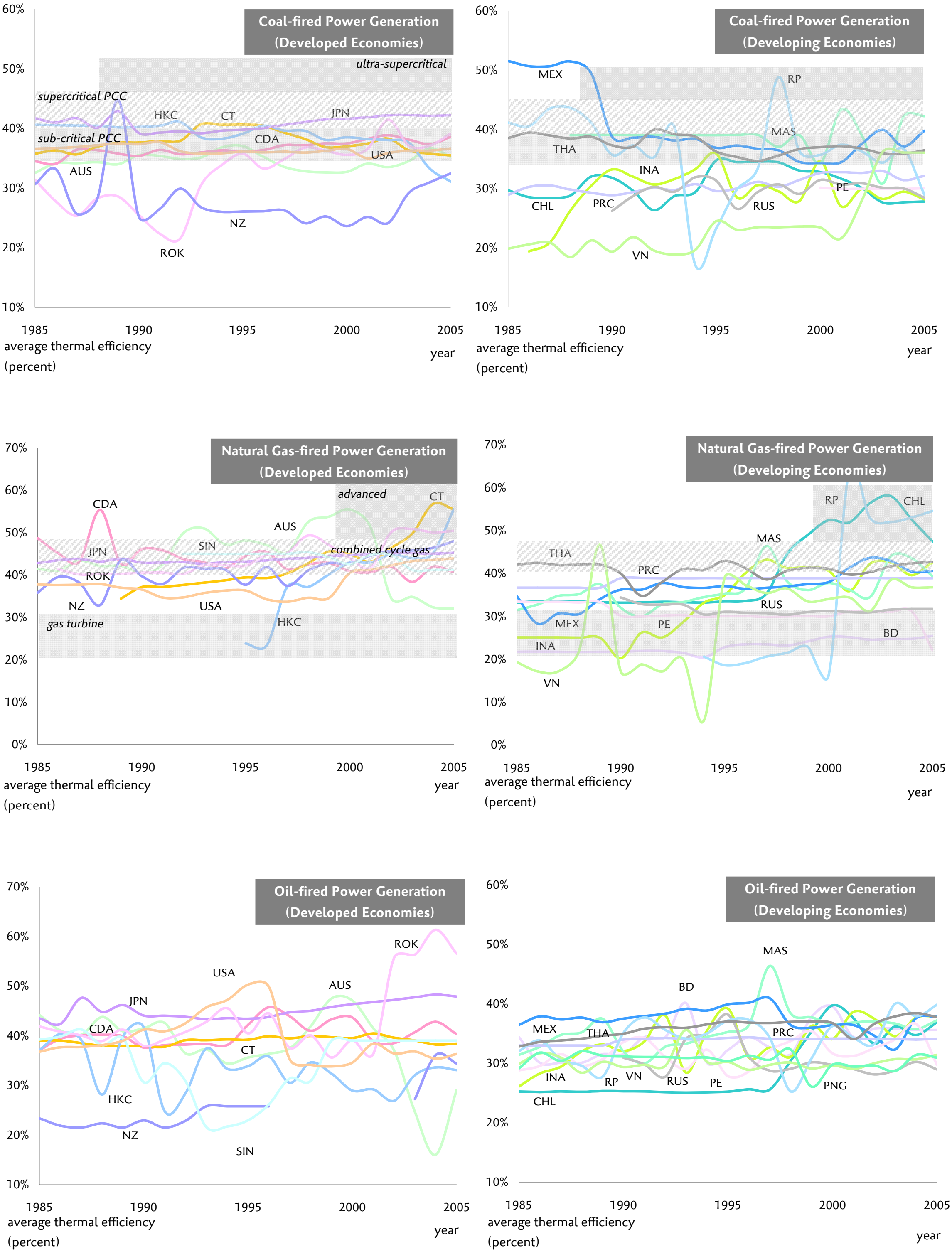
The estimated average thermal efficiency of fossil fuel power generation is in fact quite different depending on an economy's generation mix. The average overall thermal efficiency of fossil fuel power generation improves as a greater percentage of electricity is generated from high efficiency power units. Chile, for example, increased its share of natural gas-fired power generation from 35 percent (1997) to 47 percent (2005). Over this time period, the average thermal efficiency of fossil fuel power generation has increased from 33 percent to 40 percent since the average thermal efficiency of natural gas-fired power plants is higher than that of coal-fired power plants. A similar switch, from coal and/or oil to natural gas, has also improved the average thermal efficiency in the Philippines, Singapore, Thailand, the United States, and Viet Nam. In Malaysia and New Zealand, however, average thermal efficiency has increased by replacing natural gas-fired power generation plants with higher efficiency coal-fired power generation over the past five years.

14.1 Methodology for calculating thermal efficiency

OPERATING CONDITIONS AND TECHNOLOGY UTILISATION

The thermal efficiency of a power generation unit is also affected by its operating conditions. Power plants running under full load conditions normally operate at the highest thermal efficiency. Furthermore, the utilisation and penetration of highly efficient technology is another factor affecting the average thermal efficiency of fossil fuel power generation.

To eliminate the mix effect and determine the impact of operational conditions and technology utilisation, it is important to evaluate the thermal efficiency of power generation by energy-type.



15.1 **Thermal efficiency by energy type in APEC economies (1985 to 2005)**

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SYSTEM LOSSES: T&D AND PLANT OWN USE

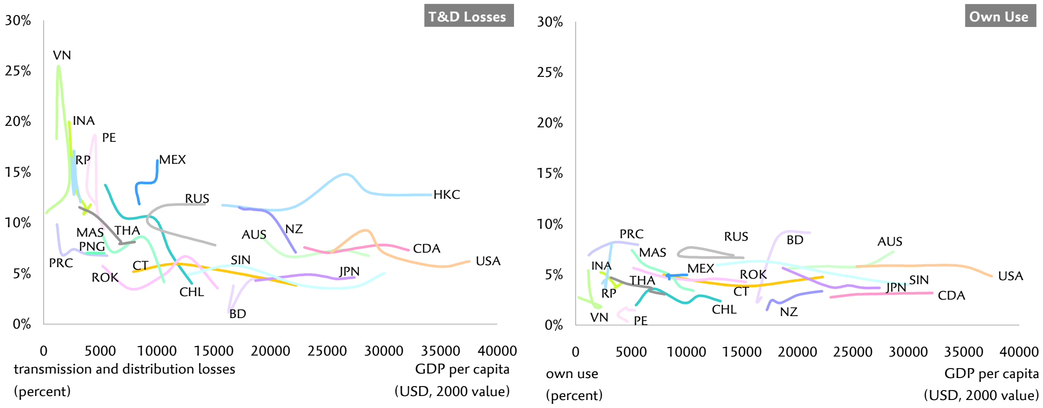
TRANSMISSION AND DISTRIBUTION (T&D) LOSSES

Transmission and distribution (T&D) losses are defined as the share of electricity losses between sources of supply (generating stations), points of distribution, and ultimate end-users. Generally, with increasing GDP per capita, T&D losses decrease [16.1]. From 1985 to 2005, T&D losses rapidly decreased for developing economies, while the losses in developed economies stabilised regardless of an increase in GPD per capita. In 2005, the T&D losses among APEC economies ranged from 3.5 percent (Korea) to 12.1 percent (Philippines). T&D losses in Hong Kong are relatively higher, compared with other economies in a similar GPD per capita range, because these losses include both T&D and plant own use losses.

In order to compare T&D losses among APEC economies, a benchmark indicator was created. The benchmark indicator represents a weighted average of the T&D losses in APEC [17.1]. Based on available data, the benchmark indicator shows that T&D losses in the region have decreased from 7.3 percent (1985) to 6.9 percent (2005).

In developed economies, T&D losses are lower than the benchmark indicator. Only New Zealand shows relatively higher T&D losses. Conversely, T&D losses in some APEC developing economies are higher than the benchmark. As a whole, however, T&D losses tend to get smaller and differences among economies have narrowed in the last twenty years.

This trend is reflective of government strategies. Some developing economies have made specific efforts to cut down their T&D losses. For example, the Philippines launched a System Loss Reduction Programme in 1994 when the Anti-Pilferage of Electricity and Theft of Electric Transmission Lines/ Materials Act (Republic Act 7832) was introduced.[h] Since the programme launched, T&D losses have reduced steadily even though they are still higher than the benchmark indicator. In 1997, China also carried out a power grid network renovation and construction project to reduce T&D losses. As a result, T&D losses in China have stabilised around the benchmark indicator level for the past ten years.



16.1 **T&D losses and plant *own use***

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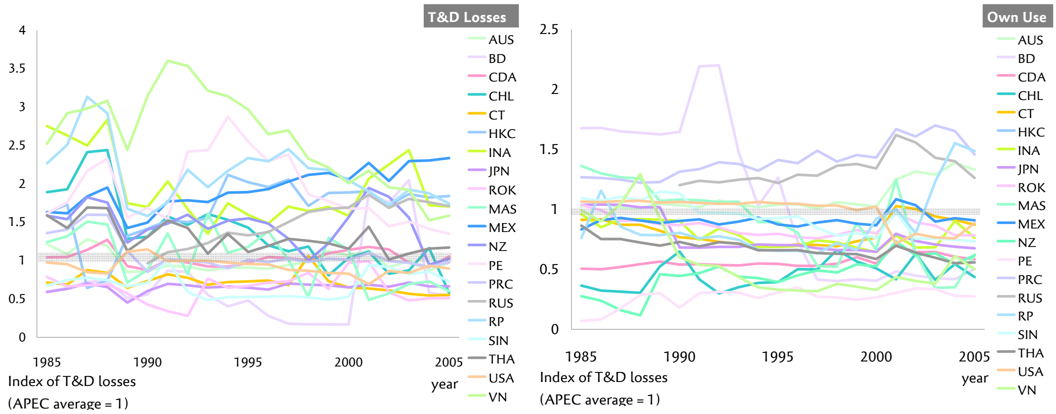
LOSS IN PLANT OWN USE

Similar to T&D losses, plant own use losses are measured as the share of electricity used to run plants while they generate electricity. Compared to T&D losses, plant own use losses have not decreased considerably (between 1985 and 2005) with increasing GDP per capita [16.1]. Rather, other factors (generation mix, plant size, and operating conditions) may have more of an impact on plant own use losses.



17.1 **Index: T&D losses and plant *own use* (APEC average = 1)**

APERC 2008

A benchmark indicator for plant own use losses was also developed for the region. Among APEC economies, the average share of plant own use, which reached 5.5 percent in 2005, slightly increased by 0.2 percent over the past two decades. In 2005, plant own use losses in Australia, China, Russia, and the Philippines were higher than the benchmark indicator. Economies that have a substantial share of their energy mix come from hydro (Canada, New Zealand, Chile, and Peru) tend to have lower own use losses. China, on the other hand, shows a consistently higher loss than the benchmark indicator because a significant share of its electricity is generated from small sized and/or less efficient coal-fired power plants. Power plants in Russia operate at poor or unfavourable conditions because of insufficient maintenance, as such explaining its higher own use losses.

THERMAL EFFICIENCY BY ENERGY-TYPE

The thermal efficiency trends of coal-fired, natural gas-fired, and oil-fired power generation are shown in [15.1]. A range for the thermal efficiency of the technologies that are commonly used in APEC is also included, so as to provide a conceptual idea of the technological level that each APEC economy has reached.

It is important to note that since oil has been steadily replaced by other types of energy, research and development on oil-fired power generation technology has been limited during the past two decades. Thus, efficiency improvements in oil-fired power generation have been confined to retrofitting or equipment replacement in existing plants.

THERMAL EFFICIENCY TREND OF COAL-FIRED POWER GENERATION

The average thermal efficiency of coal-fired power generation in the APEC region, currently at 35 percent, has not significantly improved over the past two decades. The efficiency improvement in some economies has been offset by an efficiency decrease in other economies. In 2005, the efficiency of coal-fired power generation ranged from about 28 percent (Chile) to 42 percent (Japan and Malaysia).

[h] *Republic Act 7832 mandated electric utilities to reduce system loss to ensure that power rates reflect actual consumption. (Philippine Department of Energy)*

An improvement in thermal efficiency for coal-fired power generation, as found in ten[i] APEC economies, is generally the result of:

- using less energy intensive equipment for newly installed power plants, such as supercritical PCC technology;
- shutting down old, small, and inefficient power plants (particularly in China);
- retrofitting or upgrading existing power plants with better equipment, such as adding an extra air heater surface in the boiler; [j]
- upgrading equipment from subcritical to super or ultra-supercritical PCC technology; and/or
- restoring the power plant to operate at optimum conditions, such as restoring the plant to design conditions or having regular maintenance.

In the United States, however, coal-fired power generation efficiency has stayed relatively the same, at around 37 percent, over the past twenty years.[k] This is linked to a

- policy shift to promote gas-fired power generation and
- lack of major capacity additions in new coal-fired power generation.

In essence, some of the R&D interest to improve power plant efficiency or develop new technology for coal-fired power generation was lost. The installed capacity for coal-fired power generation increased flatly from 303 GW (1989) to 313 GW (2005), while the installed capacity for natural gas-fired power generation experienced a robust growth from 166GW to 383GW.[l] Recently, however, the United States has resumed various R&D programmes, such as FutureGen Alliance and Clean Coal Technology Roadmap, for coal-fired power generation in order to reduce carbon dioxide and other GHG emissions. [m,n]

In Peru, coal has been used for power generation since 2000. The installed capacity of coal-fired power generation, approximately 269 MW (2005), comprises less than 10 percent of the economy's total thermal installed capacity.[o] In 2005, the average thermal efficiency for this generation was approximately 30 percent, which is below the average subcritical PCC power unit range.

The decreasing efficiency trends found in Chile, Hong Kong, Indonesia, and the Philippines can be explained partly by the operating conditions of power plants within these economies. Some of these power plants are run for middle or peak-load demand; as such, they operate below their optimal thermal efficiency level, which is reached during base-load operation. Additionally, some power plants may lack sufficient maintenance or may not have been upgraded/retrofitted even though they have been operational for more than twenty years.

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[i] *These economies include Australia, Canada, China, Indonesia, Japan, Korea, Malaysia, New Zealand, Russia, and Viet Nam.*

[j] *Pradip Kumar Mandal 2006*

[k] *Subcritical PCC technology is commonly used for coal-fired power generation.*

[l] *Energy Information Administration 2007*

[m] *Energy Information Administration 2007*

[n] *NETL 2004*

[o] *Ministry of Energy and Mines 2008*

THERMAL EFFICIENCY TREND OF NATURAL GAS-FIRED POWER GENERATION

Unlike coal-fired power plants, less energy intensive technologies have been adopted for natural gas-fired power generation in the past twenty years, specifically combined-cycle gas turbines. In 2005, the average thermal efficiency of natural gas-fired power plants in the APEC region was around 40 percent. It ranged from about 25 percent (Brunei Darussalam) to 56 percent (Hong Kong and Chinese Taipei). [15.1] shows that at least fourteen APEC economies used combined-cycle gas turbines for natural gas-fired power generation and six economies used advanced design technologies, which have a thermal efficiency up to 60 percent. [p,q]

Less efficient (than average) natural gas-fired power generation is normally found in APEC economies with rich natural gas resources (Brunei Darussalam, Peru, and Russia).

THERMAL EFFICIENCY TREND OF OIL-FIRED POWER GENERATION

Compared to coal-fired and natural gas-fired power generation, the thermal efficiency level of oil-fired power generation among APEC economies is less diverse. From 1985 to 2005, the average efficiency of oil-fired power generation in the APEC region was maintained at around 39 percent, which is actually higher than the average efficiency of coal-fired power generation. In 2005, the efficiency of oil-fired power plants ranged from about 29 percent (Australia and Russia) to 57 percent (Korea).

In 2005, oil-fired power generation accounted for less than 16 percent of total fossil fuel electricity generation in APEC, mainly to supply peak demand load. Since oil-fired power generation has been replaced by other types of energy, the efficiency of oil-fired power generation in these economies has not improved much in the past two decades. In fact, there has been a decrease in oil-fired generation efficiency in Australia, Hong Kong, Chinese Taipei, and the United States.

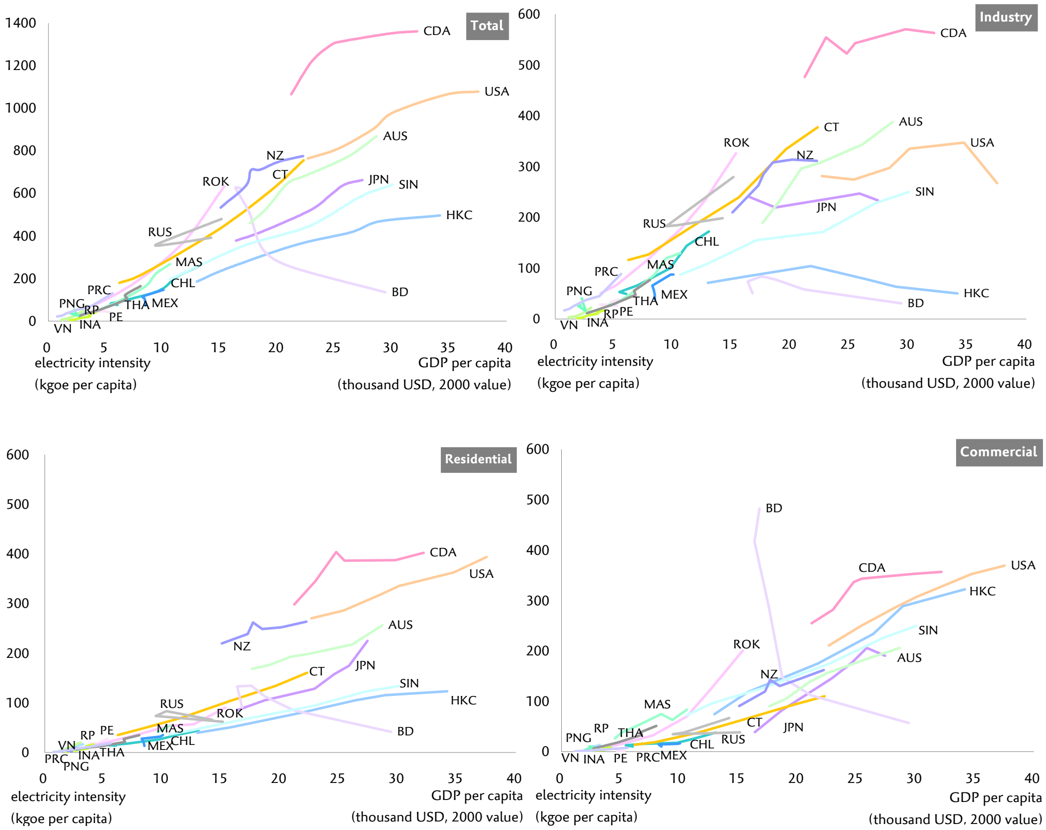
The remaining six economies (Indonesia, Japan, Mexico, Papua New Guinea, Peru, and Singapore) generate more than 21 percent of their fossil fuel based electricity from oil. From 1985 to 2005, the efficiency of oil-fired power plants in Indonesia and Japan improved the most, by 1.9 percent and 0.5 percent per year, respectively.

[p] *These economies include Canada, Chile, Hong Kong, Indonesia, Japan, Korea, Malaysia, Mexico, New Zealand, the Philippines, Singapore, Thailand, Chinese Taipei, and the United States.*

[q] *These economies include Chile, Hong Kong, Korea, New Zealand, the Philippines, and Chinese Taipei.*

ELECTRICITY INTENSITY: DEMAND SIDE TRENDS

Final electricity demand in the APEC region has grown at an average of 3.4 percent per annum in the past fifteen years, from 5,718 TWh in 1990 to 9,386 TWh in 2005. By sector, industry took the largest share in total electricity demand (42 percent), followed by residential (28 percent), and commercial (24 percent) in 2005.



20.1 **Sectoral electricity intensity (1980 to 2005)**

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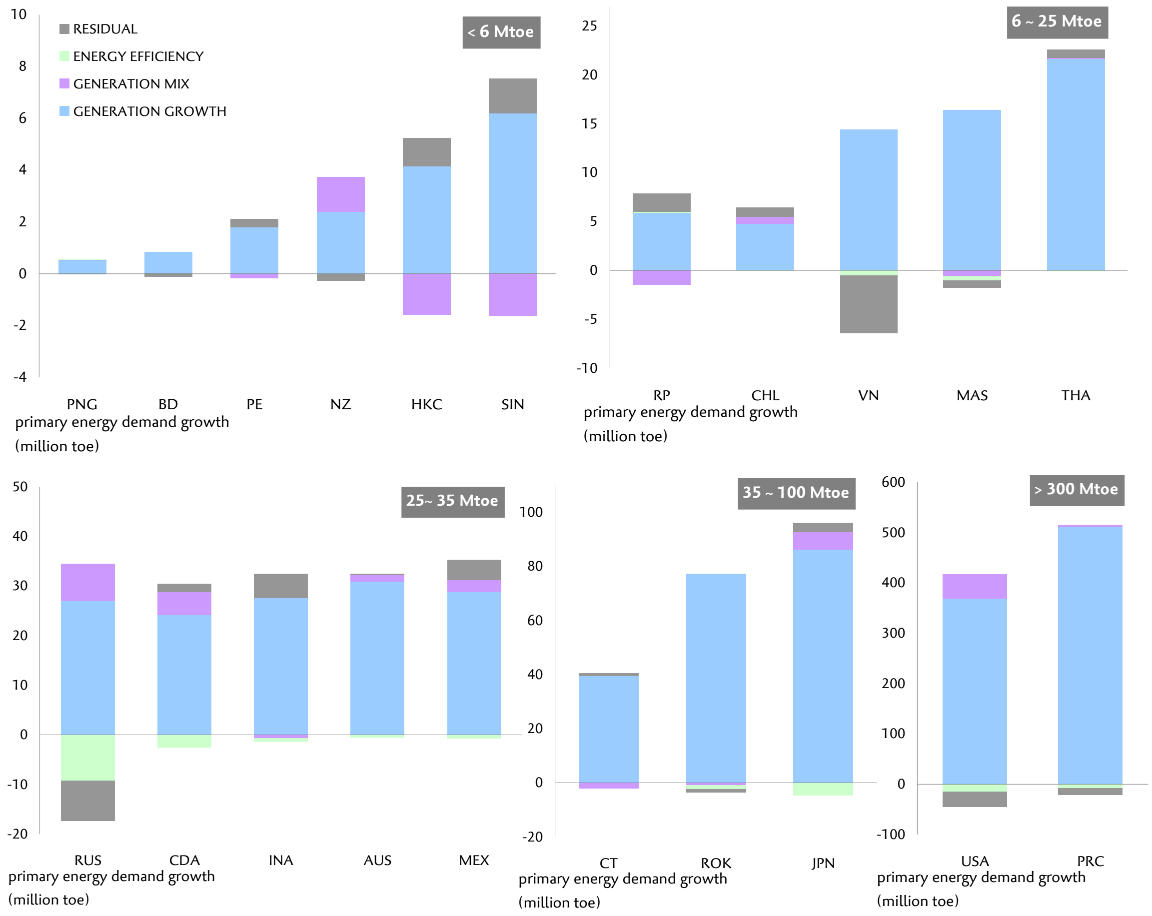
In the industry sector, electricity intensity shows a positive trend with GDP per capita in most APEC economies. The electricity intensity trend is fairly similar up to a GDP per capita of approximately USD 10,000; however, it becomes more diverse as GDP per capita increases above USD 10,000. Canada's data reveals a relatively high energy intensity in the industry sector. Hong Kong is the only APEC economy that shows a decreasing trend in industrial electricity intensity.

The electricity intensity of the residential and commercial sectors shows a robust increase at lower levels of GDP per capita. As GDP per capita increases, the electricity intensity grows until reaching a certain intensity threshold.

THE PRIMARY ENERGY DEMAND IN THE POWER SECTOR

To further understand the factors that have affected primary energy demand growth in the power sector, from 1985 to 2005, a decomposition analysis for each APEC economy is conducted. The impact of generation growth (G), changes in generation mix (S), and energy efficiency changes (EE) on primary energy demand growth, over the twenty-year period, are shown in [21.1].[r]



21.1 **Decomposition analysis: Impact of generation growth, generation mix, and energy efficiency on primary energy demand growth (by factor)**

Russia's analysis covers data from 1995 to 2005.
APERC 2008

In general, the data shows that generation growth has the strongest impact on primary energy demand growth. In contrast, changes in generation mix have had either a positive or negative effect on the growth of primary energy requirements. For instance, in New Zealand, changes in generation mix have positively contributed to a growth in primary energy requirements, while generation mix changes in Hong Kong have contributed to a decrease in primary energy requirements. Similarly, changes in energy efficiency (or thermal efficiency of generation) have had either a positive or negative effect, at differing degrees, on the growth in primary energy requirements.

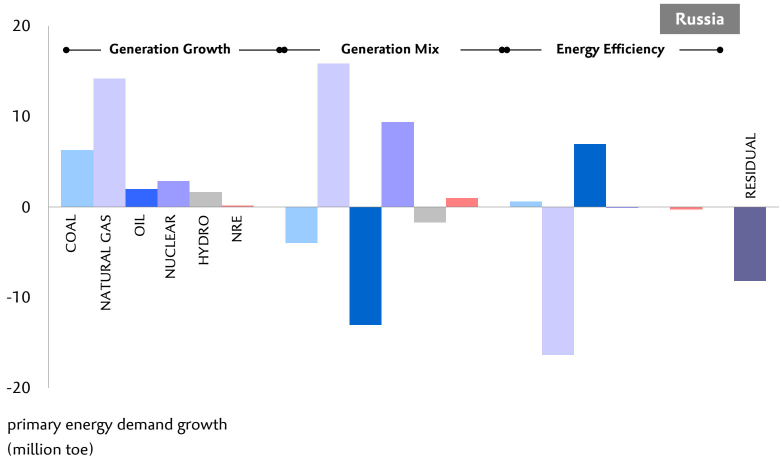
[r] *From 1985 to 2005, primary energy demand for power generation in the APEC region increased at 4.8 percent per year, from 994 Mtoe to 2,531 Mtoe.*

A RUSSIAN PERSPECTIVE:

DECOMPOSITION ANALYSIS BY ENERGY-TYPE

Energy-type also affects primary energy demand growth to different extents. A detailed decomposition analysis is conducted to identify the factors that have affected primary energy demand growth in the power sector. In this analysis, changes in primary energy demand growth are classified into combinations of six energy-types (coal, natural gas, oil, nuclear, hydro, and NRE) and three factors (generation growth, changes in generation mix, and changes in energy efficiency). The analysis is conducted for Russia between 1995 and 2005.

The data shows how the variable combinations influenced the growth of the power sector's primary energy requirements [22.1]. From 1995 to 2005, the primary energy requirements in Russia's power sector increased by 7 percent (17 Mtoe). This relatively small growth is linked to an economic slow-down, which continued until the early 2000s. Despite the relatively small increment, a major shift occurred in the generation mix. The share of natural gas and nuclear substantially increased at the expense of coal, oil, and hydro. The increase in natural gas' share results from an increase in the utilisation factor of existing natural gas-fired power generation. In fact, this contributed to the power sector's overall thermal efficiency improvement.



22. 1 **Decomposition analysis by energy type: Russia (1995-2005)**

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FINDINGS

Since the power sector is the largest consumer of total primary energy in APEC, energy efficiency improvements in this sector can greatly contribute to the enhancement of energy security and sustainable development.

The energy efficiency of fossil fuel power generation varies widely in APEC. Among developed economies, it ranges from 35 percent (Australia) to 44 percent (Japan). In developing economies, the disparity is wider, from 26 percent (Brunei Darussalam) to 42 percent (the Philippines). In fact, the thermal efficiency of six developing economies (the Philippines, Thailand, Chile, Malaysia, Mexico, and Viet Nam) falls within the thermal efficiency range of developed economies in the region. This may suggest that factors other than an economy's economic development level can affect the overall thermal efficiency of fossil fuel power generation.

The analysis in this chapter identified two factors as the main drivers that affect the overall thermal efficiency improvement in an economy. These factors include:

- energy switching that corresponds with an adoption of efficient technologies and
- changes in the operating conditions of power plants.

For example, thermal efficiency in several economies (Chile, Philippines, Singapore, Thailand, the United States, and Viet Nam) has improved because of a switch from coal and/or oil to natural gas. In other economies, Malaysia and New Zealand, average thermal efficiency has increased by replacing natural gas-fired power generation with higher efficiency coal-fired power generation.

In Russia, the efficiency of natural gas-fired power generation improved significantly because of an increase in the utilisation ratio of existing natural gas-fired power plants.

Despite its importance, thermal efficiency improvements have made a relatively small contribution to slowing down the power sector's primary energy demand growth. As the decomposition analysis showed, the growth in the power sector's primary energy demand is largely attributed to an increase in power generation. This finding implies that a strategy to

(1) identify areas for energy efficiency improvement and

(2) create conditions to realise potential energy savings in the power sector is necessary.

PERSPECTIVE OF THE FUTURE:
A SCENARIO ANALYSIS

INTRODUCTION

Power generation within each of the twenty-one economies of the APEC region is distinctive. This uniqueness stems from each economy's energy resource endowment, degree of generation mix diversification (in terms of number and respective share of energy-types), and the technology used to convert this primary energy into electricity.

Understanding the historical context of energy efficiency improvement within each APEC economy and the region as a whole is essential to determine the likelihood of future scenarios and the potential to achieve energy efficiency targets. Without a good understanding of each economy's status, future policy development could prove inadequate to meet necessary improvements to help reduce energy demand and improve both local and global air quality. As such, in the previous chapter, relevant historical data related to power sector efficiencies was reviewed.

This chapter aims to forecast the potential for APEC economies to capitalise on technological trends of higher efficiencies in thermal power generation to achieve targets of greater energy savings and emissions reduction.

POWER SECTOR EMBRACES EFFICIENCY IMPROVEMENT: THE RATIONALE

As of 2005, power generation accounts for at least 32 percent of total primary energy demand and thermal power generation accounts for 71 percent of total generation for the region. Specifically, coal and natural gas contribute 48 percent and 18 percent, respectively, to total power generation.

By 2030, it is projected that power generation will account for 45 percent of total primary energy demand. Yet, APEC is projected to become a net importer of natural gas by 2015 and coal by 2030.

These statistics suggest that the power generation sector plays a key role in ensuring the region's energy security. APEC's diversity in energy resource endowment, together with the technological trend of higher efficiencies in thermal power generation, provides each economy with different motivations to transform the sector.

The APEC region's ability to be a *premier forum for facilitating cooperation, trade, and investment* and the fact that its member economies account for approximately 55 percent of the world's GDP makes this diverse region a potential frontrunner in terms of energy efficiency improvement in the power generation sector.

A PROSPECTIVE FUTURE: ENERGY SAVINGS AND CARBON DIOXIDE REDUCTION

In practice, there are several means to achieve energy efficiency improvements in the power sector. For example, a future path towards regional energy efficiency improvement can be paved through mutual cooperation to minimise the power sector's energy intensity by 2030. This would require any similarities amongst economies that might facilitate the adoption of new technology and the potential for retrofitting and/or repowering of existing plants to be taken advantage of for the betterment of the region as a whole.

Assuming this ideal scenario, what can the benefits be in 2030, in terms of energy and CO_2 emissions reduction, if an energy efficiency improvement of 10 to 15 percent occurred over the remaining 22 years until 2030?

To calculate this savings potential, data from APERC's *APEC Energy Demand and Supply Outlook 2006 – Economy Review*, specifically projections of electricity demand and required generation capacity to the year 2030, are referenced. These projections also draw on the analysis of IEA data that is presented in the previous chapter. Fuel and CO_2 price assumptions are derived from average IEA price data [26.1].

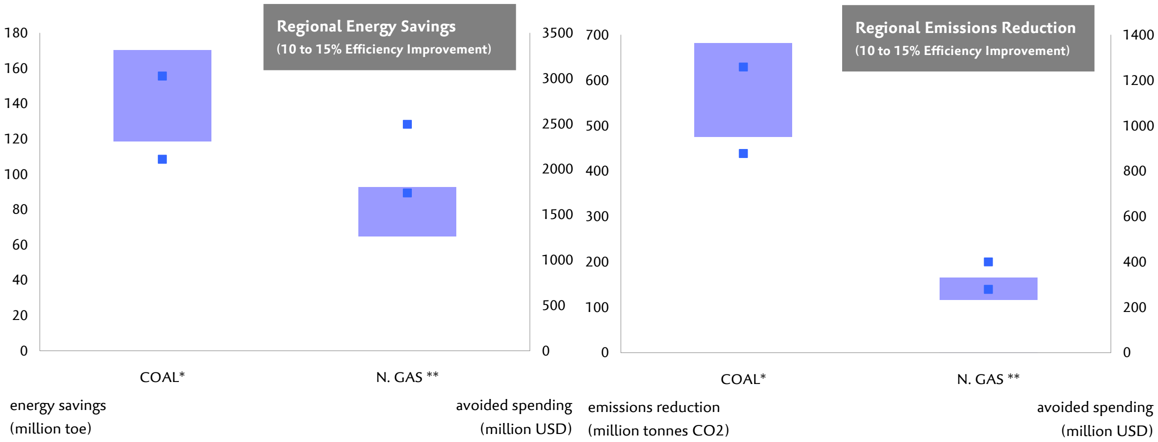
In terms of potential energy savings, a 10 to 15 percent energy efficiency improvement in coal-fired power generation can avoid approximately 119 to 170 Mtoe, while natural gas-fired power generation improvements can avoid 65 to 93 Mtoe. In monetary terms, this can provide the region from USD 3,848 to 5,521 million in energy savings (USD 2,110 to 3,026 million in coal savings and 1,739 to 2,495 in natural gas savings).

The following assumptions are used in this analysis:

- Coal price = USD 55.2 per tonne
- Natural gas price = USD 380.1 per toe (NCV basis)
- Avoided carbon emissions= USD 20.0 per tonne

The 2006 average price for Korea, Mexico, and the United States was used as a proxy for APEC's average price for coal and natural gas.

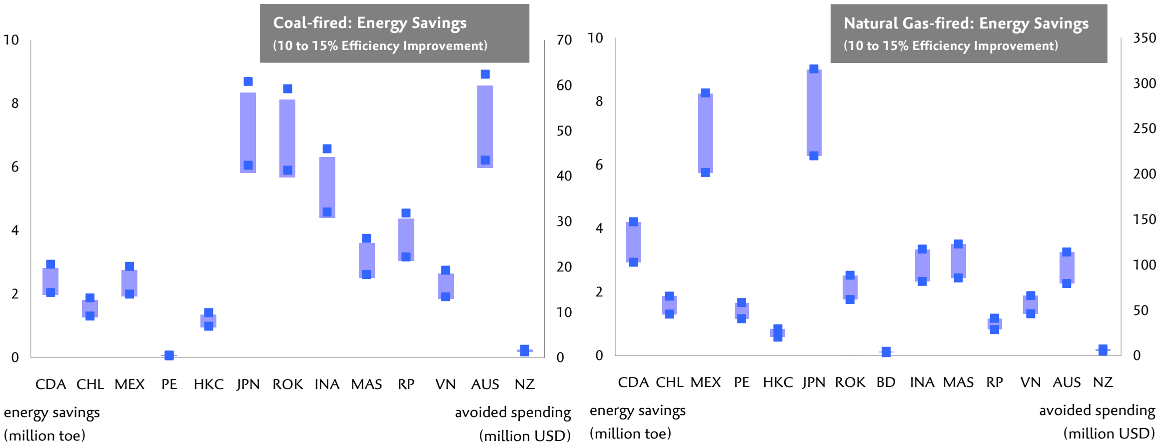
26.1 **Scenario analysis: Price assumptions**



26.2 **Regional energy savings and emissions reduction range (10 to 15 percent efficiency improvement)**

**Excludes data for BD, PRC, PNG, RUS, SIN, CT, THA, and USA. **Excludes data for PRC, PNG, RUS, SIN, CT, THA, and USA.*
APERC 2008

Potential savings are not limited to energy. An energy efficiency improvement can also abate considerable CO_2 emissions. The greatest regional benefit comes from an improvement in coal-fired power generation, with a savings potential of 475 to 682 million tonnes of CO_2 or approximately USD 877 to 1,259 million. Natural gas-fired power generation has a savings potential of 116 to 166 million tonnes of CO_2 or approximately USD 279 to 400 million. In total, these savings are equivalent to abating the total projected CO_2 emissions in 2030 for Southeast Asia's transport sector. [a]



27.1 **Economy-specific energy savings range (10 to 15 percent efficiency improvement)**

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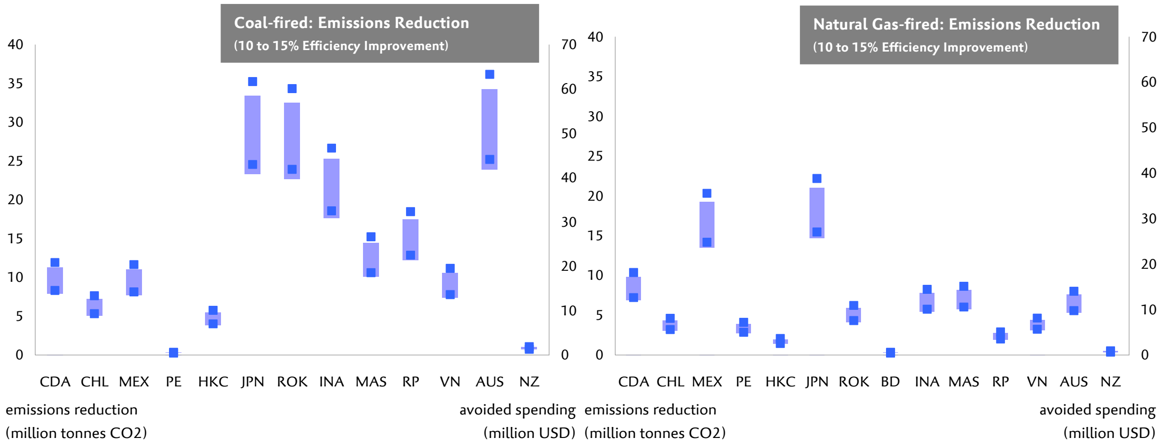
In general, the greatest potential savings for APEC, both energy and emissions reduction, comes from an improvement in coal-fired power generation. The magnitude of benefit is significantly larger than that for natural gas-fired because coal-fired power generation accounts for the largest share of generation capacity within the region

At an economy level, however, the potential savings vary greatly. In certain cases, improvements in natural gas-fired power generation efficiency produce larger energy savings. [b]

[a] *These economies include Brunei Darussalam, Indonesia, Malaysia, Singapore, Thailand, and Viet Nam.*

[b] *These economies include Chile, Japan, Korea, Mexico, and Peru.*



28.1 **Economy-specific emissions reduction range (10 to15 percent efficiency improvement)**
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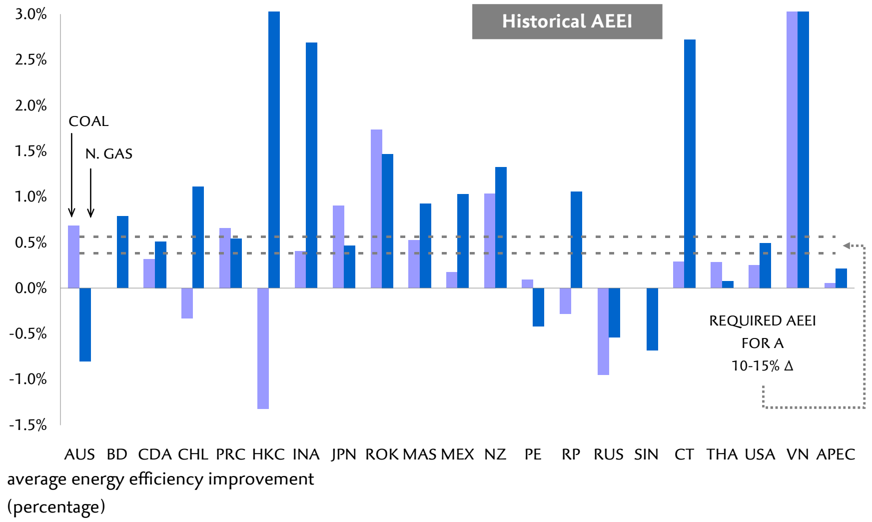
A review of the results reveals several factors that seem to influence the extent of these benefits. In this model, an economy's size of electricity generation and the growth rate of demand from 2005 to 2030 (by energy-type) influence the difference. Although fuel prices remain constant in this analysis, real-world trends suggest that fuel prices can also impact the degree of benefit, in some cases reducing the likelihood of improvement due to below prime pricing schemes.

It is important to note that this investigation reflects the results of an ideal case, where all economies achieve the same target. In reality, however, a 10 to 15 percent efficiency improvement target seems overly optimistic. In order to achieve this improvement, each economy would be required to have from a 0.38 to 0.56 percent annual energy efficiency improvement (AEEI). Historical data reveals that in the past 25 years, the APEC region has only had a 0.06 percent AEEI for coal-fired power generation and a 0.21 percent AEEI for natural gas-fired power generation.



29.1 **Historical AEEI vs required AEEI for a 10 to 15 percent efficiency improvement**

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Specifically, nine economies have a historical AEEI for coal-fired power generation that is lower than the 0.38 percent required for a 10 percent energy efficiency improvement.[c] In terms of natural gas-fired power generation, five economies have a lower historical AEEI.[d] Thus, this data suggests that a 10 percent regional improvement is questionable and a 15 percent improvement seems highly unlikely.

It is important to note that this is not necessarily the case for all member economies; historical improvements and future improvement potential are different. Some economies may have already exhausted the efficiency improvement options that are low effort. However, attractive low effort options may still be available for developing economies.

PROSPECT OF PROGRESS: THE POWER GENERATION LEEI INDEX

As a means to further understand the likelihood that an economy will invest in energy efficiency improvements, the Power Generation Likelihood of Energy Efficiency Improvement (LEEI) index was created. This index is designed to capture the importance of risk factors that can encourage an economy to improve the efficiency of its power sector.

Each economy's investment strategy is inevitably different, based on the magnitude of their future supply risk. The LEEI index captures the risks involved with an economy's import dependency (in terms of the magnitude of resource required and the importance of these imports to total power generation), electricity demand growth (infrastructure constraints), the age structure of its existing generation capacity, and its average thermal efficiency level. An overview of the methodology used to design this index is discussed in Appendix *III*.

To effectively determine potential investment strategies, it is also important to differentiate between energy-types. As such, a separate

[c] *These economies include Canada, Chile, Hong Kong China, Peru, the Philippines, Russia, Chinese Taipei, Thailand, and the United States.*

[d] *These economies include Australia, Peru, Russia, Singapore, and Thailand*

LEEI analysis for coal-fired and natural gas-fired generation was conducted, since technology and investment paths are quite different between feedstocks.

Six APEC economies (Australia, Canada, Japan, Korea, Indonesia, Mexico, and the United States) are included in this analysis. These economies were chosen because they represent the highest levels of demand for coal-fired and/or natural gas-fired power generation, for which all factor analysis could be conducted.

Each economy is ranked based on its potential for improvement. This serves as a tool for determining not only whether investment in efficiency is beneficial, but also what type of generation can provide the highest benefit in terms of reducing future supply risk.

The final value acquired from this index is normalised on a 0 to 100 scale. A higher LEEI index score reflects a greater future level of supply risk for power generation. A score closer to 0 implies that an economy is less likely to make an improvement in energy efficiency, while a value close to 100 implies that the economy is highly likely to invest in efficiency improvements. Specifically, economies that have a score above 50 are recommended to invest, while those with a score above 75 are required to invest in order to avoid significant future generation risks.

FINDINGS

In interpreting the results, it is important to note that this index is founded on the premise of potential benefits associated with risk reduction and only suggests the likelihood of energy efficiency investment. Economies with less incentive to make improvements, in terms of risk-reduction benefits, may still choose to invest in further efficiency improvements.

Taking that as a given, the results of the Power Generation LEEI index show that the aforementioned economies have greater incentive to invest in energy efficiency improvements in coal-fired power generation than in natural gas-fired power generation.

COAL-FIRED POWER GENERATION LEEI INDEX (2005-2030)

RANK		PER CAPITA CONSUMPTION OF IMPORTED COAL (POWER GEN)	POWER GEN DEMAND GROWTH (CUMULATIVE)	PLANT AGE STRUCTURE (EXISTING GEN CAPACITY)	POWER GEN ENERGY IMPORT DEPENDENCY	THERMAL AVG EFFICIENCY LEVEL (2005)	SCORE
1	USA	4.4	12.8	40.0	0.6	5.0	62.7
2	ROK	18.0	16.0	18.0	4.5	5.0	61.6
3	INA	0.0	16.0	39.7	0.0	5.0	60.7
4	AUS	0.0	13.1	31.1	0.0	5.0	49.1
5	JPN	13.7	6.3	10.2	4.9	2.5	37.6

30.1 **Coal–fired power generation LEEI index (2005-2030)**

APERC 2008

The risk associated with coal-fired power generation is much higher, having an average score of 54.3, while natural gas-fired has an average risk score of 38.3.

NATURAL GAS-FIRED POWER GENERATION LEEI INDEX (2005-2030)							
RANK		PER CAPITA CONSUMPTION OF IMPORTED NATURAL GAS (POWER GEN)	POWER GEN DEMAND GROWTH (CUMULATIVE)	PLANT AGE STRUCTURE (EXISTING GEN CAPACITY)	POWER GEN ENERGY IMPORT DEPENDENCY	THERMAL AVG EFFICIENCY LEVEL (2005)	SCORE
1	JPN	18.0	2.5	21.3	4.6	2.5	48.9
2	ROK	18.0	6.4	7.3	5.3	5.0	41.9
3	MEX	13.9	12.3	8.5	3.5	2.5	40.6
4	CDA	0.0	14.0	10.8	1.6	2.5	39.4
5	INA	10.5	16.0	11.0	0.0	2.5	29.5
6	USA	8.1	1.6	13.8	1.1	5.0	29.5

31.1 **Natural gas-fired power generation LEEI index (2005-2030)**

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The trend towards higher coal-fired power generation risk is linked primarily to each economy's existing generation capacity age structure. Within the five economies reviewed, on average, over 60 percent of coal-fired power generation capacity is older than 20 years. In contrast, less than 30 percent of natural gas-fired power generation is older than 20 years. Given that the average retirement age of a plant is from 30 to 35 years, a significant share of coal-fired power generation will require replacement, retrofitting, or refurbishing by 2030. This will provide an opportunity to enhance the current efficiency of generation within each economy.

Another important observation from the index is that the per capita consumption of imported energy is higher for natural gas than coal. Economies that currently have a high value for this indicator (14 to 18 points) and lack sufficient purchasing power (in comparison to neighbouring economies) may want to initially focus their energy security strategy on reducing this intensity. As resources become more constrained within the region, this indicator will become considerably more important. Without sufficient bargaining power, economies that fall within the higher risk zone for this indicator may suffer significant supply shortages.

As previously mentioned, although the results from this index may not suggest the necessity for improvement, all economies can benefit, to some degree, by an improvement in energy efficiency.

FUTURE EE IMPROVEMENT: POTENTIAL PATHS TO ENHANCE ENERGY SAVINGS

While seemingly unrealistic for all APEC economies, in terms of historical efficiency trends, a 10 to 15 percent energy efficiency improvement in the power sector, over 25 years, is actually a low target.

The promotion of strategies and mechanisms to reach higher efficiencies is an essential component to curb the anthropogenic contributions to climate change.

Based on the power generation LEEI index, an investor can reason whether or not to plan for an efficiency improvement and narrow the options, in terms of energy input, by which to do this to provide significant risk-reduction benefits.

However, further evaluation and forecasting must be done in order to determine the exact path to accomplish the required efficiency improvement in the desired time allotment. To meet future generation requirements, there are two major options:

(1) retrofit/ refurbish old capacity and

(2) add new capacity.

If improvement is desired at a gradual pace, to reduce the initial financial burden, retrofitting or refurbishing of existing generation may be the most useful path. Alternatively, technology leap-frogging, through the adoption of a substantial share of new higher-efficiency generation capacity, can provide faster results for economies that have the capability of making this transition. The proceeding chapters will delve into the potential for either path.

THE GRADUAL APPROACH:

RETROFITTING AND REFURBISHING

INTRODUCTION

Generating power at high efficiencies can make economic sense for both utilities and an economy. In terms of utilities, higher efficiencies can reduce energy input costs and may also enable higher power system reliability. As for an economy, it will benefit when lower generation costs are passed to consumers; while, less use of fossil energy may conserve reserves and reduce carbon emissions.

Thermal power plant efficiency deteriorates with time. As such, utilities need to continuously take action to regain and increase efficiency, where technically possible. The rate of this efficiency decline differs by power plant due to specifics in plant design and incorporated features, and most importantly on how well the plant is maintained. Any compromise to the best practice in plant maintenance and operation could work against sustained efficiency levels.

The objective of this chapter is to assess the potential energy savings and avoided carbon emissions (of existing power plants) that can be attainted by increasing power plant efficiency through retrofitting and refurbishing. The time horizon of the analysis is 25 years, from 2005 to 2030.

The analysis is limited to coal-fired power plants because they constitute a significant share of total power generation capacity in the APEC region (28.7 percent in 2005, excluding China), and have a higher efficiency improvement potential, among fossil fuelled power plants. The retrofit analysis includes specific case studies of Australia, Malaysia, Mexico, and the United States.

Technological advancements in coal-fired power generation, as explained in the Leapfrogging Approach: Technological Road Map chapter, offer substantial efficiency improvement potential by replacing or refurbishing existing plants in the future. Natural gas-fired power generation, which has naturally progressed to use more combined cycle technologies, has relatively higher conversion efficiencies than coal-fired power plants of comparable size. Analysis on the efficiency improvement and potential energy savings of natural gas-fired power plants is not done in this chapter.

Declining plant performance, over time, is often an indicator that a retrofit may be in order. Better plant maintenance and operation is vital for retrofit measures to generate any efficiency improvement. Most retrofit options are well proven and may have significant positive returns on investment.

DEFINITION

The words retrofit and refurbish are often used interchangeably in the context of power plant energy efficiency improvements. Moreover, the word refurbish is often used within the retrofit framework, and vice-versa. In this analysis, retrofit and refurbish are defined as follows:

RETROFIT

33.1 **Retrofits: Conditions and timing**

To retrofit is to increase the energy conversion efficiency of a power plant to its maximum potential by replacing and/or adding new plant components and parts of higher performance and sophistication. Retrofitting is implemented on plants that have a significant economic life remaining. Efficiency improvements linked to retrofitting remain within the thermodynamic capacity limits of a plant's design.

REFURBISH

To refurbish is to transform certain parts of a power plant to new or close to new conditions, thus to recondition or replace parts of a plant. In an extreme case, a retrofit transforms the entire power plant to conditions close to new. The latter case is an option at the end of the planned or natural economic life of a power plant, thereby giving the plant a second economic life at higher efficiencies, if so desired. This is often achieved more economically than building a new plant.

Refurbishing a coal-fired power plant to other specifications, where technically possible, may be more economically viable than building a new plant when decommissioning of the existing plant has been ruled out. The economic advantages include the potential to re-use, on a case-by-case basis, existing plant infrastructure and specific parts (the plant's steel structure; coal receiving, handling, and storage facilities; cooling water supply; and certain parts of the coal pulveriser plant). Re-use of an existing power plant site is an advantage, particularly when finding new sites for coal-fired power plants has become more difficult. [a] Moreover, the refurbished plant is likely to exceed the environmental performance of the replaced plant.

34.1 **Advantages of refurbishing**

Timely investment to refurbish plant components, in conjunction with retrofit measures that incorporate technological advancements and the implementation of best practices in maintenance and operation, may actually offset the plant aging process and extend the life of a plant.

A power plant will, however, inevitably reach a point in time when it has reached the end of its useful planned or natural economic life. Possible options, in such a case, are to decommission the plant, restore the site to its original state, transform the site for other use, or give the plant a new life through refurbishment.

The technological possibilities, in the case of an overall power plant refurbishment, are quite broad, since entire parts of a plant are subject to replacement or reconditioning. This may include major components of a plant, such as the entire steam cycle.

Refurbishment options include: reconditioning a plant to condition as new; converting a power plant to a higher class in terms of thermal efficiency; and converting a power plant to achieve a specific carbon emission and nitrous oxide emission performance.[b] One type of coal-fired power plant refurbishment is power plant repowering, the conversion of a coal-fired power plant into a natural gas-fired combined cycle plant. Power plant repowering, however, will require a supply of natural gas.

SAVINGS: ENERGY AND CO_2 EMISSIONS REDUCTION

RETROFITTING

Retrofit measures that can lead to energy savings include: improvements in a plant's heat recovery system (economisers) and heat transfer (including condensers); better energy management supported by variable control of energy consuming devices (such as pumps and fans), better combustion control, and the use of more efficient turbine blades (when blade replacement is necessary).

It is imperative to reinstate other plant components that are retained from the retrofit process to design conditions to ensure the effectiveness of a retrofit. Maintenance measures, particularly to contain steam leaks, are important, as well as operating the plant according to best practice principles.

[a] *Finding new sites has become more difficult due to NIMBY concerns and high land acquisition costs.*

[b] *This list is not all inclusive.*

Actual areas that have retrofit potential need to be identified on a plant by plant basis, since a power plant's condition is dependent on its design and operation. In this analysis, however, power plants are assumed to be in the comparable condition, as such, requiring the same type of retrofit.

RETROFIT ANALYSIS: ASSUMPTIONS

As previously mentioned, this analysis examines the potential retrofit-based energy savings that can be accrued from 2005 to 2030. The following assumptions apply:

Coal-fired power plants in the 0 to 9 years age group (in 2005) will require at least one minor retrofit in the next 25 years.

Coal-fired power plants in the 10 to 19 years age group (in 2005) will require at least one major retrofit in the next 25 years.

Coal-fired power plants in the 0 to 19 years age group (in 2005), with capacities greater than 100 MW, are assumed to have the greatest retrofit potential in the 25 year time frame from 2005 to 2030. The region's total coal-fired power generation capacity in this age group is approximately 109,000 MW.

	0 - 19 YEARS
	> 100 MW
AUSTRALIA	7,900
BRUNEI	-
CANADA	2,850
CHILE	1,339
HONG KONG, CHINA	2,708
INDONESIA	800
JAPAN	28,869
KOREA	10,900
MALAYSIA	9,421
MEXICO	3,800
NEW ZEALAND	960
PHILIPPINES	3,679
PAPUA NEW GUINEA	-
CHINESE TAIPEI	8,597
UNITED STATES	26,646
VIET NAM	750
TOTAL	109,218

35.1 **Power plant capacities in the 0 to 19 years age group, greater than 100 MW**

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The retrofit measures listed in [36.1] are considered the first set of options that can give the most efficiency gains and are assumed to be applicable to all economies in this analysis. Furthermore, power plants, at the time of retrofit, are assumed to be in a condition such that efficiency gains, as stated in [36.1], can be achieved.

Since better plant maintenance is a requisite for the retrofit-based plant efficiency improvements, measures to restore plants to design conditions are included.

All power plants in the 0 to 19 years age group are assumed to implement minor retrofit measures (measures A.1 and A.2). Power plants in the 10 to 19 years age group will also implement major retrofit measures (measures B). Major retrofit measures are assumed to be more viable in relatively older plants.

MEASURES	EFFICIENCY IMPROVEMENT (PERCENT)
A.1 CHANGES TO OPERATIONAL SETTINGS:	
LOW EXCESS AIR OPERATION	1.22
IMPROVED COMBUSTION CONTROL	0.84
A.2 RESTORE PLANT TO DESIGN CONDITIONS:	
MINIMIZE BOILER TRAMP AIR	0.42
REINSTATE ANY FEEDER HEATERS OUT OF SERVICE	0.46-1.97
REFURBISH FEEDER HEATERS	0.84
REDUCE STEAM LEAKS	1.10
REDUCE TURBINE GLAND LEAKS	0.84
B. RETROFITTING IMPROVEMENTS:	
EXTRA AIR HEATER SURFACE IN BOILER	2.10
INSTALL NEW HIGH EFFICIENCY TURBINE BLADES	0.98
INSTALL VARIABLE SPEED DRIVES	1.97
INSTALL ON-LINE CONDENSER CLEANING SYSTEM	0.84
INSTALL NEW COOLING TOWER FILM PACK	1.97
INSTALL INTERMITTENT ENERGISATION TO ELECTROSTATIC PRECIPITATORS (ESPs)	0.32

36.1 **Retrofit measures and corresponding efficiency improvement (percent)**

Mandal 2006

Retrofit analysis: Savings potential

[37.1] shows the annual energy and carbon emissions reduction savings, from both minor and major retrofit measures, for power plant capacities in the 0 to 19 year age category.[c] These savings are assumed to take place in the second half of the 25 year time horizon.

[c] *In this analysis, energy savings are solely comprised of coal savings.*

	ENERGY	CO2	ENERGY	CO2
	[MILLION TOE]	[MILLION TONNES]	[MILLION USD]	[MILLION USD]
AUSTRALIA	0.6	0.8	57.4	15.8
CANADA	0.2	0.3	23.4	6.4
CHILE	0.1	0.1	9.6	2.6
HONG KONG, CHINA	0.2	0.3	22.2	6.1
INDONESIA	0.1	0.1	6.6	1.8
JAPAN	2.1	2.7	197.1	54.2
KOREA	0.8	1.0	73.3	20.2
MALAYSIA	0.6	0.8	55.8	15.4
MEXICO	0.3	0.4	30.5	8.4
NEW ZEALAND	0.1	0.1	7.9	2.2
PHILIPPINES	0.2	0.3	22.9	6.3
CHINESE TAIPEI	0.6	0.8	58.0	15.9
UNITED STATES	2.2	2.9	210.7	57.5
VIET NAM	0.0	0.1	4.5	1.2
TOTAL	8.2	10.7	778.5	214.1

37.1 **Annual energy and CO_2 emissions reduction savings**

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REFURBISH

Potential areas that can benefit from refurbish measures are quite broad. The options range from the gradual and timely refurbishment of plant components (to be done in conjunction with plant retrofitting to extend plant life), which is more straightforward, to a more complex refurbishment that entails converting a power plant that has reached the end of its economic life to a higher class.

With the more straightforward option, it is possible to extend the lifetime of a power plant's current capacity. In this case, plant efficiency can be maintained at plant design conditions.

However, as a result of current advancements in coal-fired power plant technology, the latter option should be considered. If this option is taken, it is important to consider a time frame for the phase-out of power plants and the introduction of higher efficiency coal-fired power plants. These plants should reflect the latest, state of the art, technology such as supercritical and ultra-supercritical coal-fired power plants; fluidised bed coal-fired power plants, where appropriate; and other coal-fired power plant technologies.

Plant retrofitting, in conjunction with refurbishing and better plant maintenance and operation, may yield benefits beyond that of energy savings and emissions reduction. Complementary benefits may include increased power plant availability and thus improved system reliability. Power plant availability is particularly critical in systems where reserve margins are tight.

Depending on system reserve conditions, benefits of reliable plant availability can range from avoiding costly rolling brown outs to the possible deferral of new reserve capacity construction. Benefits beyond energy savings are not discussed in this analysis and should be analysed on a system-by-system basis.

37.2 **Additional benefits: Power plant availability/ reliability**

The following analysis addresses the potential energy savings of this latter option and compares it against the most likely alternative, which would be the continued maintenance of existing capacity at current efficiency levels. Due to data limitations, an analysis to address the economics of this specific scenario is beyond the scope of this study. [d]

REFURBISH ANALYSIS: ASSUMPTIONS

This analysis assumes that a certain share of subcritical power plants, which have reached the end of their economic life (20 years and older as of 2005) and have efficiency levels in the lower 30 percent range, are refurbished and converted to supercritical and ultra-supercritical power plants with an average efficiency in the 44 percent range.

This transition will occur within the 25 year timeframe from 2005 to 2030.

With regard to the region's generating capacity, approximately three fourths of the installed coal-fired power generation (356,000 MW) is in the 20 years and older age group [38.1].

Most of this capacity, 289,000 MW, is located in the United States. Australia and Canada have the next largest capacity of plants in this age category with 23,000 MW and 13,000 MW, respectively.

	20-24 YEARS	25-29 YEARS	30-34 YEARS	35-39 YEARS	≥ 40 YEARS	TOTAL
AUSTRALIA	10,505	4,000	3,480	2,140	2,035	22,160
CANADA	1,325	1,230	4,146	5,430	875	13,006
CHILE	-	-	-	125	338	463
HONG KONG, CHINA	3,900	-	-	-	-	3,900
INDONESIA	6,250	924	251	-	-	7,425
JAPAN	3,625	1,175	1,256	1,775	787	8,618
KOREA	6,240	-	825	-	-	7,065
MEXICO	900	-	-	-	-	900
PHILIPPINES	300	-	-	-	-	300
CHINESE TAIPEI	1,550	-	300	1,100	125	3,075
UNITED STATES	47,217	61,364	64,884	46,770	69,089	289,324
VIET NAM	440	-	105	-	-	545
TOTAL	82,252	68,693	75,247	57,340	73,248	356,780

38.1 **Capacity of plants in the 20 years and over age group**

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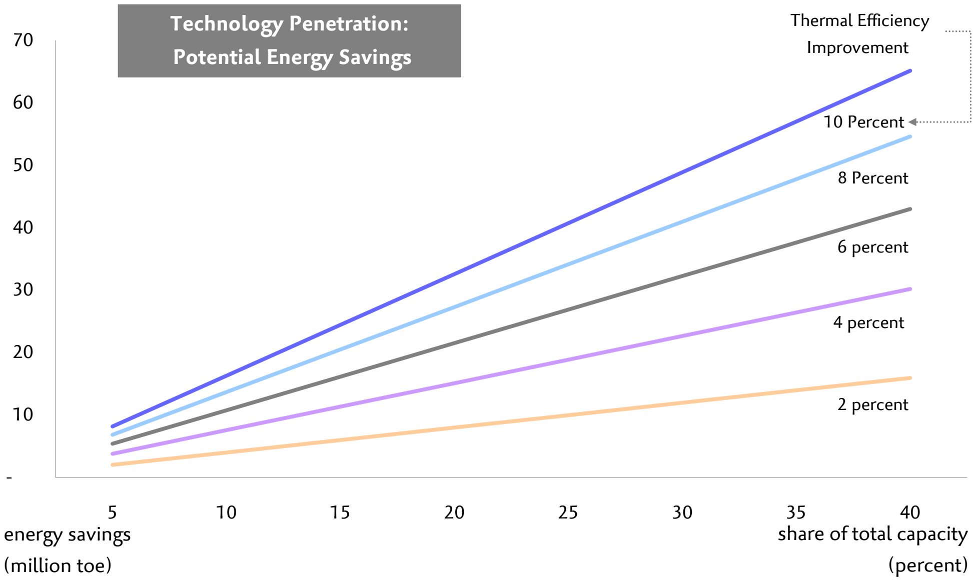
[d] *This analysis would require plant level data, as well as a technical assessment.*

Refurbish analysis: Savings potential

Potential energy savings from refurbishing measures are shown in [39.1]. The x-axis represents the degree of technology penetration among the selected coal-fired power plant capacity (20 years and older age grouping) in the 25 year timeframe from 2005 to 2030.



39.1 **Potential energy savings by level of technology penetration over a 25 year timeframe**

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Based on the aforementioned assumptions, [39.1] shows that a 20 percent penetration of supercritical and ultra-supercritical power plants, with an average efficiency gain of 8 percent, will yield an annual energy savings of 28 Mtoe. It is worth noting that at higher efficiency improvement levels, marginal savings are smaller.

RETURN ON RETROFIT INVESTMENT: ENERGY SAVINGS AND CO_2 EMISSIONS REDUCTION

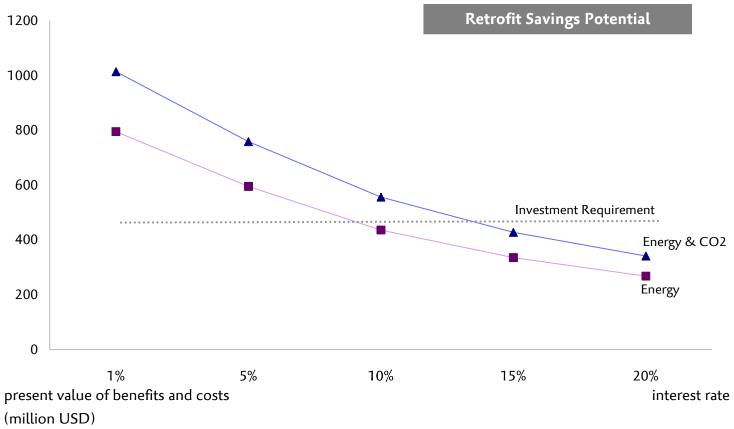
To understand the magnitude of savings, the net present value for the retrofit improvements previously mentioned, is estimated for four economies (Australia, Malaysia, Mexico, and the United States). The following assumptions are used to determine the present value of retrofit improvements in this analysis:

- 15 year payback period
- 5 percent discount rate
- Coal price = USD 66.0 per tonne [e]
- Avoided carbon emissions= USD 20.0 per tonne
- Benefit to cost ratio = 1.3 (over 15 years time frame)

Using these assumptions, two cases are assessed: *Case 1* represents the present value of only energy savings and *Case 2* represents the present value of both energy and CO_2 emissions reduction savings. The results from this analysis are shown in [40.1].

In Australia, the total retrofit capacity potential is approximately 7,900 MW. This would require an investment of USD 458 million. In [40.1], the difference between the horizontal grey line (total investment requirement) and the purple (*Case 1*) and blue (*Case 2*) lines represents the net present value of each benefit. In *Case 1*, the net present value of energy savings, at a 5 percent interest rate, is USD 137 million. In *Case 2*, the net present value of both energy and CO_2 emission reduction savings is USD 301 million.

In terms of positive returns on investment, the analysis shows that at lending rates above 10 percent, investment exceeds potential benefit savings.



40.1 **Retrofit savings potential: Energy and CO_2 emissions reduction**

This figure assumes a 7,900 MW retrofit with a 5 percent discount rate, over 15 years.
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For comparison, the energy and CO_2 emissions reduction savings for Malaysia, Mexico and the USA are shown in [41.1].

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[e] *The highest coal price in the region during 2006 was used as a proxy for APEC's future average coal price.*

	AUS	MAS	MEX	USA
PLANT CAPACITY FOR RETROFIT (0-9 YEARS), MW	7,900	9,420	3,800	26,645
TOTAL COST (MILLION USD)	458	446	243	1,682
PV BENEFIT (MILLION USD), 15 YRS, 5% DISCOUNT RATE:				
CASE 1 - PV BENEFIT IN ENERGY SAVINGS	595	579	316	2,187
CASE 2 - PV BENEFIT IN ENERGY AND CO2 REDUCTION SAVINGS	759	739	403	2,769
NET PRESENT VALUE (NPV) - CASE 1	137	134	73	505
NET PRESENT VALUE (NPV) - CASE 2	301	293	160	1,086

41.1 **Net present value of retrofit improvements in Australia, Malaysia, Mexico, and the United States**

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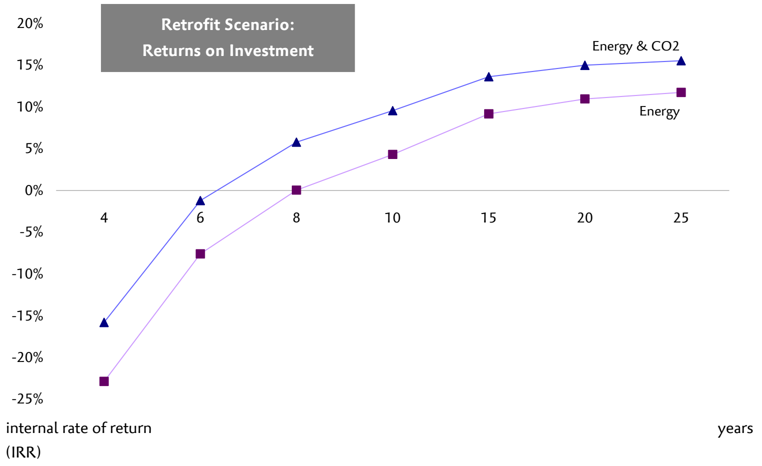
The internal rate of return (IRR) and corresponding investment term length for retrofit *Case 1* (annual coal savings) and *Case 2* (combined coal and CO_2 emission reduction savings) are shown in [41.2]. The difference in IRR for *Case 1* and *Case 2*, based on the aforementioned estimates and assumptions, is approximately 4 percent. It is important to note that the efficiency gains achieved in the initial years after the retrofit need to be well maintained over the investment period to achieve the desired IRR.



41.2 **Returns on investment: Energy savings and combined savings in energy and CO_2 emissions reduction**

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IMPLICATIONS

Power plant retrofit and refurbish measures, as they become necessary, are imperative to regain a plant's design condition efficiency and to optimise plant conversion efficiency. The economic benefit of plant retrofits and refurbish measures can be significant in terms of energy savings. However, the economic benefit of these measures needs to be investigated on

(1) a plant-by-plant basis,

(2) a broader operational and power systems basis, and

(3) from a long term investment perspective,

to fairly account for the overall cost and benefits.

In conjunction with the best practice in maintenance and operation, plant retrofits and refurbish measures may extend the life of a power plant.

The option to refurbish power plants, at the end of their economic life, to a higher efficiency class may already be applicable to power plants that are currently in the older age groups. This study merely shows that the potential energy savings in APEC, in view of the large total capacity of older plants in the region, can be substantial. In terms of economy-level feasibility, an in-depth analysis, reflective of plant-level data, is recommended in order to gauge a precise level of savings.

THE LEAPFROGGING APPROACH:

TECHNOLOGICAL ROAD MAP

INTRODUCTION

The power sector is the region's largest energy user. Across the region, the power sector is characterised by a heavy reliance on fossil fuels, which contribute more than 70 percent to the power sector's total energy use in APEC. In other words, this may suggest that an energy efficiency improvement in the power sector, particularly on fossil fuel based power generation technologies, has the potential to greatly contribute to an overall energy efficiency improvement in APEC economies.

To understand the potential and possible areas for energy efficiency improvement, this chapter presents historical trends for the power generation technologies that have been applied in APEC. The chapter tries to characterise available technologies, including both conventional and advanced, on such aspects as thermal efficiencies, emissions, and capital investment requirements. The chapter also offers a possible future roadmap for the deployment of power generation technologies.

The discussion in this chapter is concentrated on fossil fuel power generation technologies, mainly on coal-fired power generation and natural gas-fired power generation technologies. This chapter excludes descriptions on oil-fired power generation technologies because oil-fired generation units have been largely replaced by other types of power generation technologies since the first oil crisis in 1973, and play a minor role in overall fuel use in the power sector. The chapter also excludes a discussion on conventional technologies, such as internal combustion engines, stoker, and stoker cyclones. The power generation technologies presented in this chapter include: pulverised coal combustion (PCC), fluidised bed combustion (FBC), integrated gasification combined cycle (IGCC), and combined cycle gas turbines (CCGT).

AN OVERVIEW OF POWER GENERATION TECHNOLOGY

The world's fossil fuel power generation technologies are basically divided into two types: steam turbines (ST) and gas turbines (GT).

STEAM TURBINES

In a steam turbine, coal, oil, or natural gas is burned to produce steam that is then used to drive a turbine (steam cycle). Among modern steam turbine technologies, pulverised coal combustion (PCC) is the oldest and most widely used, with capacities over 1,000 MW available. Based on steam conditions and thermal efficiencies, PCC technology is divided into three categories: subcritical, supercritical, and ultra-supercritical.

Fluidised bed combustion (FBC) is also a promising coal-based steam turbine technology. It emits less SOx and NOx than other alternatives. Essentially, grained limestone in the fluidised bed precipitates out the sulphur and a lower combustion temperature reduces NOx formation. FBC systems are also more flexible than conventional systems. However, FBC system's power generation capacity is limited to a maximum of about 300 MW, thus its application is limited to instances where mid-size power plants are appropriate and strict air pollution controls are required.

GAS TURBINES

In a gas turbine, natural gas is the preferred feedstock. It is burned to create hot gases to drive a gas turbine (gas cycle). Compared with coal combustion, natural gas is combusted at much higher temperatures (over 1538 deg C), which results in an increase in the formation of NOx in the flue gas. A major challenge to improving the thermal efficiency in gas turbines is to determine how to reduce the formation of NOx in the combustion chamber, while maintaining a high firing temperature at the turbine blade. In advanced applications, waste heat from the gas cycle, in the form of hot gas, is recycled to produce steam to generate additional electricity. This type of process is referred to as a combined cycle gas turbine (CCGT).

Integrated gasification combined cycle (IGCC) is a type of gas turbine technology that is under development for coal-fired power generation. The IGCC process does not combust coal, rather, it reacts coal with oxygen and steam to produce syngas that consists of hydrogen and carbon monoxide. This syngas is then burned to drive a combined cycle (CC) system. Since air pollutants, specifically carbon dioxide, are easier to remove and capture from pre-combusted, pressurised syngas than from post-combusted flue gas, IGCC is considered as a leading technology for clean coal combustion and carbon capture. Although currently more expensive than conventional pulverised coal combustion systems, IGCC may become cost effective if policies to limit carbon emissions are implemented.

CHARACTERISTICS OF FOSSIL FUEL POWER GENERATION TECHNOLOGIES

The characteristics of fossil fuel power generation technologies (energy input flexibility, unit size, plant efficiency (LHV), plant type, steam condition, emissions levels, and capital investment requirements) are described in [45.1,2 and 46.1]. To highlight the main characteristics of each generation technology, five aspects of generation technologies will be discussed in this section. These aspects are: energy input flexibility, unit size, thermal efficiency, emissions levels, and capital investment requirements.

	STEAM TURBINE	SUBCRITICAL PCC	SUPERCRITICAL PCC	ULTRA-SUPERCRITICAL PCC
ENERGY INPUT(S)	COAL NATURAL GAS OIL AND PETROLEUM PRODUCTS	COAL	COAL	COAL
UNIT SIZE (IN OPERATION)	≤ 1300MW	≤ 1300 MW 50-800 MW (AVG)	≤1300 MW	≥ 1000 MW
PLANT EFFICIENCY (LHV) (%)	30 - 35% (AVG)	≤40% 35 - 36% (AVG)	42 - 47% (AVG) APPROACHING 50% (DENMARK)	47 - 50% (AVG)
STEAM CONDITION				
TEMPERATURE		≈ 375°C	≥ 540°C	≥ 580°C
PRESSURE		16.5- 22.1 MPa 19 MPa (AVG)	≤22.1 MPa 24 - 26 MPa (AVG)	≥ 28 MPa
EMISSIONS				
CO (g/kWh)		0.399 - 0.430	0.374 - 0.396	0.334 - 0.376
CO2 (g/kWh)		311.55	311.55	
SO2 (g/kWh)		0.267 - 0.369	0.245 - 0.341	0.221 - 0.324
NOx (g/kWh)		0.239 - 0.258	0.224 - 0.238	0.200 - 0.226
PARTICULATE (g/kWh)		0.048 - 0.052	0.045 - 0.048	0.040 - 0.045
CAPITAL COST ($/kW)	133 - 205	580 - 2323	1190 - 2133	1640 - 2167

45.1 **Characteristics of steam turbine technology: General and PCC**

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	SUBCRITICAL CIRCULATING FBC	SUPERCRITICAL CIRCULATING FBC	PRESSURISED FBC
ENERGY INPUT(S)	COAL BIOMASS REFUSE DERIVED FUEL (RDF) AND OTHER WASTE SUBSTANCES	COAL BIOMASS RDF AND OTHER WASTE SUBSTANCES	COAL BIOMASS RDF AND OTHER WASTE SUBSTANCES
UNIT SIZE (IN OPERATION)	≤ 350 MWe	≤ 350 MWe	≤ 350 MWe
PLANT EFFICIENCY (LHV) (%)	38 - 40% (AVG)	≈ 43%	≤ 44%
STEAM CONDITION	SUBCRITICAL STEAM CONDITIONS WITH OR WITHOUT REHEAT	SUPERCRITICAL STEAM CONDITIONS WITH OR WITHOUT REHEAT	MINIMUM SUBCRITICAL STEAM CONDITIONS WITH OR WITHOUT REHEAT
EMISSIONS			
CO (g/kWh)			
CO2 (g/kWh)	310		
SO2 (g/kWh)	0.031		
NOx (g/kWh)	0.155		
PARTICULATE (g/kWh)	0.02325		
CAPITAL COST ($/kW)	1296 - 2060		

45.2 **Characteristics of steam turbine technology: FBC**

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	GAS TURBINE	GAS TURBINE COMBINED CYCLE	INTEGRATED GASIFICATION COMBINED CYCLE (IGCC)
ENERGY INPUT(S)	NATURAL GAS	NATURAL GAS	COAL COAL W/ BIOMASS AND WASTES REFINERY RESIDUES NATURAL GAS
UNIT SIZE (IN OPERATION)	250 - 300MWe		EXISTING : ≤600MW
PLANT EFFICIENCY (LHV) (%)	≈ 25% (AVG) ≤ 40%	40 - 45% (AVG) 60% [ADVANCED DESIGN (H-CLASS)]	≈ 43% ≤45%
STEAM CONDITION			
TEMPERATURE	≥ 482°C		
PRESSURE			
EMISSIONS			
CO (g/kWh)			0.098 - 0.102
CO2 (g/kWh)	186	186	302.25
SO2 (g/kWh)	0.00155	0.00155	0.04 - 0.141
NOx (g/kWh)	0.0465	0.0465	0.148 - 0.17
PARTICULATE (g/kWh)	NA	NA	0.023 - 0.024
CAPITAL COST ($/kW)	358 - 695	652 - 1172	958 - 2632

46.1 **Characteristics of gas turbine technology**

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ENERGY INPUT FLEXIBILITY

Energy input flexibility differs from technology to technology. For example, pulverised coal combustion (PCC) technology, whether operated under subcritical, supercritical, or ultra-supercritical conditions can burn various types of coal. In addition, the boiler in a PCC system can handle the replacement of a small amount of coal by biomass, refuse derived fuel (RDF), or sewage sludge during the combustion process (5 to 15 percent in co-firing).

The co-firing process, used in integrated gasification combined cycle (IGCC) systems, is designed not only to burn coal, natural gas, or refinery residues, but also to burn biomass or waste in combination with coal. The gasification process can gasify all types of coal, however low ash coals are preferred for economic reasons. Currently, commercial IGCC systems also use petroleum residues as feedstock for power generation.

Fluidised bed combustion (FBC) can be designed as either a circulating (subcritical or supercritical) or pressurised FBC system. These systems can burn a variety of fuels, including coal, biomass, RDF, and other waste substances. In addition, FBC systems are specially designed for low grade coals, though they perform more efficiently with low ash coals.

Steam turbines can use any feedstock to produce steam for power generation, such as coal, natural gas, and petroleum products. Gas turbines, however, predominately require natural gas as a feedstock for power generation.

UNIT SIZE

The unit size of different power generation technologies varies greatly. Commercially available PCC technology (subcritical and supercritical) has a maximum unit size up to 1,300 MW. Although smaller sizes are available, the minimum economic size of one unit is 300 MW. For optimum operation, the size of an ultra-supercritical PCC unit should be larger than 1,000 MW. IGCC power generation units are currently available up to 600 MW. FBC power generation units are much smaller, currently only available up to 350 MW, since they were originally developed for industrial boilers, which require a smaller scale.

THERMAL EFFICIENCY

For coal-fired power plants, thermal efficiency increases with higher steam temperature and pressure conditions. The designed thermal efficiency of coal-fired power generation technologies ranges from 35 percent (subcritical PCC technology) to 50 percent (ultra-supercritical PCC technology). The main technical challenge, in terms of improving efficiencies, is material development for the boiler and steam turbine, so that the equipment can withstand the elevated steam conditions.

With gas turbines, thermal efficiency increases as the firing temperature of the combustion gas that hits the first rotating blade of the turbine increases. Higher firing temperatures increase the turbine output, leading to greater electricity generation. The thermal efficiency of gas-fired power generation ranges from 25 percent (gas turbines) to 60 percent (advanced CCGT technology).

EMISSIONS LEVELS

Among fossil fuels, natural gas is the cleanest energy for power generation because it emits less NO_x, CO, and CO_2 emissions compared to coal and oil-fired power generation. Additionally, natural gas-fired power generation does not produce SO_x or particulate emissions.

Emissions of coal-fired power generation vary depending on the type of technology used and its thermal efficiency. Among steam turbines (PCC, IGCC, and FBC systems), FBC technology produces the least emissions, followed by IGCC systems. In terms of PCC technologies, the improvement in thermal efficiency from subcritical to ultra-supercritical also reduces the emissions from generation.

CAPITAL INVESTMENT

Capital investment requirements per kilowatt of power generation vary greatly by technology. Even within one technology, per kilowatt capital investment requirements differ greatly. The wide variation reflects differences in land acquisition cost and construction cost. Additionally, economies that lack an existing manufacturing capacity (related to power generation technology) will also have to pay a higher price for technology procurement.

The per kilowatt capital investment requirement is also dependant on a plant's size. Due to economies of scale, a larger unit capacity translates into a lower capital investment cost per kilowatt of total

Supercritical technology was first developed in the US during the 1950s. The first generation units, however, experienced problems related to reliability and operational flexibility. As such, utilities in the US chose to revert back to utilizing subcritical technology, thus curtailing further penetration of supercritical technology.

At the same time, the development and refinement of supercritical technology continued, specifically in Europe and Japan under government policies to promote the effective use of coal. As a result, supercritical technology was introduced in these countries during the early 1990s and has now become the leading technology for new power generation

47.1 **Supercritical power generation in brief** installed capacity. Therefore, in some cases, the cost difference between advanced technology and conventional units can become small, within 5 percent, if the unit size of the advanced technology is larger.

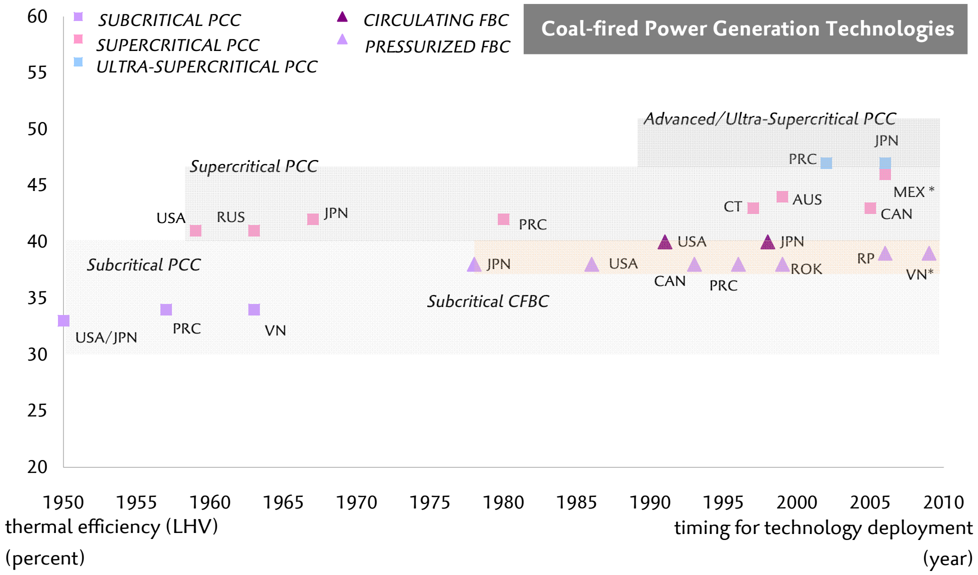
TECHNOLOGICAL EVOLUTION AND ITS DEPLOYMENT

The selection of power generation technology is affected by a number of factors. These factors may include an economy's electricity demand outlook, domestic availability of energy sources, energy prices, location of a plant, unit output of a specific technology, and load factors.

The aforementioned factors can affect the final power generation technology selection process differently in each APEC economy. With a focus on coal-fired power generation technologies, this section reviews the historical deployment of advanced power generation technologies within several APEC economies and examines factors that have affected technology choice.

[48.1] shows the initial deployment (installation) of PCC (subcritical, supercritical and ultra-supercritical) and FBC (pressurised, and circulating) technologies within several APEC economies. The grey area in the figure represents a thermal efficiency range for several power generation technologies.[a]

The data reveals that the deployment of advanced technology is not directly related to an economy's economic development level. For example, China installed supercritical PCC technology in 1980. In contrast, Australia, which has an income that is six times higher than that of China, commissioned its first supercritical PCC power plant in 1998.



48.1 **The initial deployment of PCC and FBC technologies in APEC (1950-2010)**

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[a] *The thermal efficiency shown in the figure does not represent the economy's average thermal efficiency. It offers a range for the thermal efficiency of certain types of technology.*

It is important to note that early adoption of advanced technologies does not suggest an economy-wide efficiency improvement. The figure only shows the timing for the first introduction of PCC and FBC technologies by type.

The energy resource endowment of an economy, on the other hand, can provide some insight into power generation technology choice. In Australia, for example, PCC technology, operated at subcritical conditions, comprises the largest share of installed coal-fired power generation. Since Australia is a major coal producer and coal is available at a relatively low price (compared with other energy inputs), generators in Australia have historically not had much incentive to install energy efficient generation technologies.

In contrast, Japan's early adoption of supercritical technology in 1967, was linked to the economy's relatively small domestic resource endowment, and thus its need for efficient utilisation of energy resources. Since almost 100 percent of Japan's coal demand is met by imports, it is more economical to run a coal-fired power plant with a higher efficiency. Therefore, power generators in Japan have a higher incentive to install advanced technologies for new plants.

Policies on energy conservation or efficiency improvement also affect technology choice. China, for example, declared in the 1980's that the conservation of energy resources is a basic goal of its energy policy, and started using supercritical PCC technology for power generation. In addition, the Chinese government has encouraged technology transfer to enhance the domestic manufacturing production of parts and reduce the manufacturing cost of power plant equipment. The Chinese government has also supported the establishment of research and development laboratories to help further the development of advanced power generation technologies. Recently, the Chinese government encouraged the use of supercritical and ultra-supercritical PCC technology for power generation.

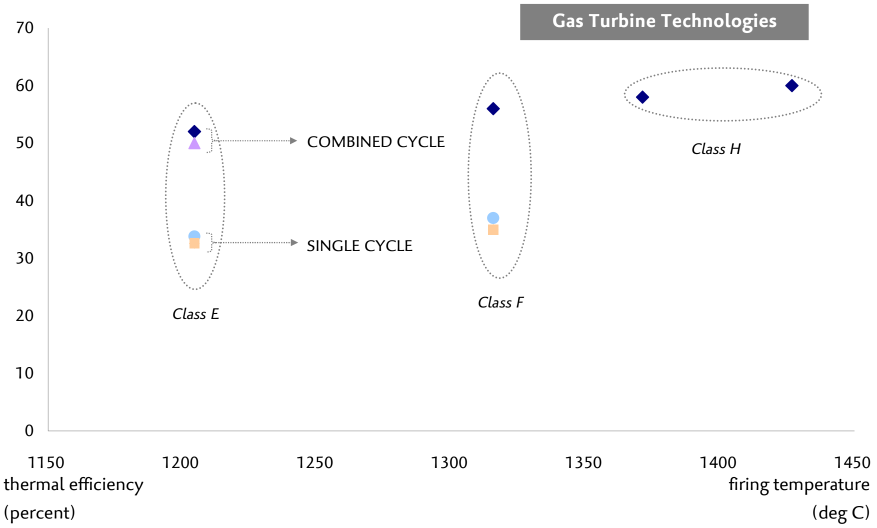
NATURAL GAS-FIRED GENERATION

In 1950, the first gas turbine for power generation was deployed in the USA. It was a 3.5 MW combined cycle gas turbine. Since then, technological advances, through the application of high grade engine materials and cooling technology borrowed from the aircraft industry, have continuously increased firing temperatures.

During its first few applications, combined cycle systems consisted of a steam turbine, as the main power generator, with a small sized gas turbine taking up a supplementary role. At that time, exhaust gas from the gas turbine was used as combustion air for the boilers. At present, exhaust gas is more effectively used through a heat recovery steam generator (HRSG) system.

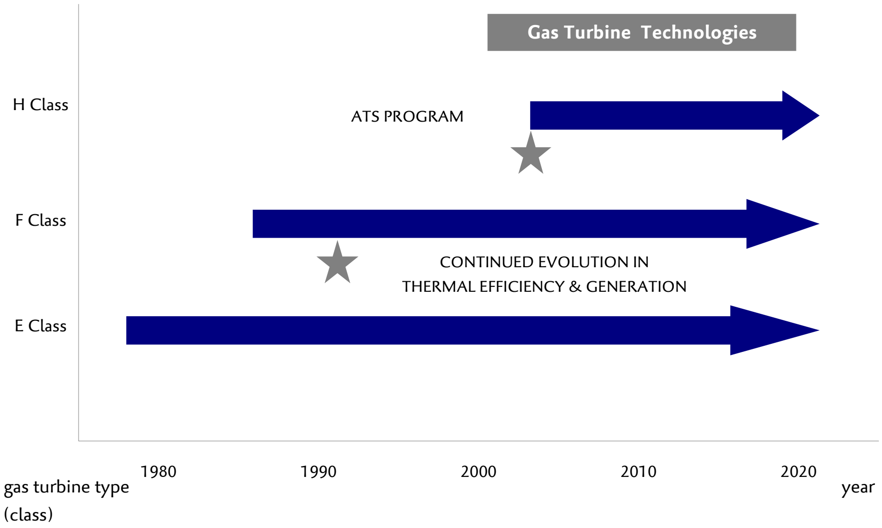
In the 1970s, as a result of an increase in turbine output and the development of HRSG, gas-fired combined cycle systems transitioned from supplementary to stand alone systems. Higher power densities and lower emissions characteristics also contributed to a gain in popularity within the power generation sector.

As a model of the evolution of gas turbine technology, General Electric, a world leader in turbine technology, is used as an example in [50.1]. The most advanced E-class combined cycle turbine, put in commercial use in the 1970s, has a thermal efficiency of 52 percent and an electricity output of 225 MW. Due to the fuel price escalation of the 1970s and early 1980s, R&D for more efficient gas turbines was encouraged. This resulted in the commercial operation of the F-class turbine in 1990. Currently, the most advanced F-class turbine has a thermal efficiency of 56 percent and an output generation capacity of 400 MW. This advancement was brought on mainly by an increase in firing temperature, from 1204 to 1316 deg C (2200 to 2400 deg F).



50.1 **Gas turbine technology evolution**

General Electric



50.2 **Gas turbine technology research, development, and deployment**

General Electric

Technological innovation to increase the thermal efficiency of gas turbines, past the F-class, has been furthered by the Advanced Turbine System (ATS) Program.[b] The Program, started in 1992, is a partnership

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[b] *The grey stars in the figure represent the timing for the first commercial installation of each technology.*

between the US government and industry. Its initial goal was to achieve a turbine thermal efficiency of 60 percent and single digit NOx emissions (in parts per million). In 2003, the first commercial deployment of an H-class turbine, which meets these targets, was realised in the UK. The performance increase associated with H-class turbines resulted from the use of innovative technology (closed loop steam cooling, single crystal super-alloy casting, and thermal barrier ceramic coating for turbine components), which enable the firing temperatures to reach to 1427 deg C (2600 deg F).

At present, the F-class turbine is the preferred option for gas-fired combined cycle power plants. This trend is expected to continue because the higher capital cost of the H-class turbine will slow its market penetration rate. In terms of the E-class turbine, it is still used in instances of smaller electricity generation demand because of its reasonable cost performance.

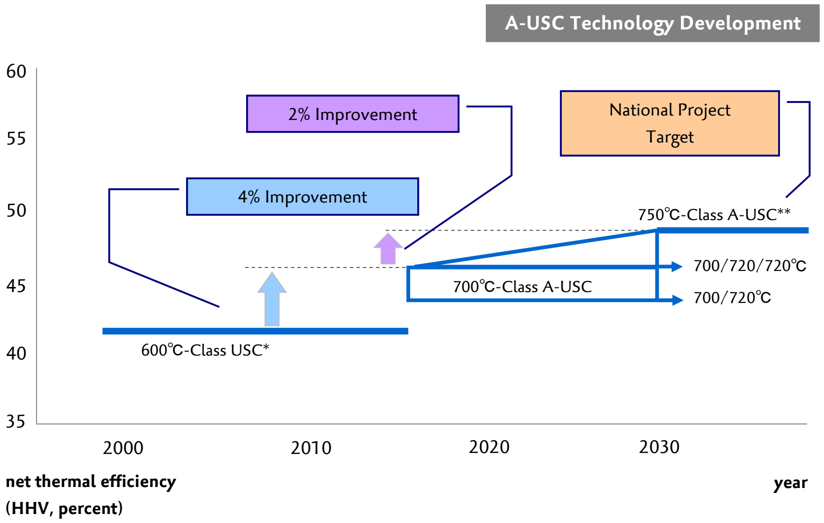
TECHNOLOGY ROAD MAP

To improve performance, in terms of thermal efficiency and air emissions reduction, R&D for pulverised coal and natural gas combustion technology has been made continuously during the past 90 and 60 years, respectively. As a result, these technologies have technically matured and become commercially proven.

Currently, PCC supercritical steam turbine technology and gas-fired combined cycle F-class turbine technology are considered the best practice technologies in the market. Ultra-supercritical steam turbines and gas-fired combined cycle H-class gas turbines are considered state of the art technologies, with a thermal efficiency of 50 percent and 60 percent, respectively. At present, FBC technology plays a limited role in spite of the potential for broader deployment in the future. IGCC still remains at the development stage.

Reflective of an expected increase in coal use and the relative advancement of gas related technology, future efforts towards technological innovation may focus on coal-fired power generation technology rather than natural gas. From this perspective, the proceeding discussion focuses on three potential paths for technological development in the mid-term, from now towards 2015 to 2020.

In technology-development path one, technology development continues beyond the current state of the art technology. Progress towards this path is already underway, with a target for the next coal-fired technology at 35MPa and steam conditions of 700 deg C (called advanced ultra-supercritical), and a firing temperature target of 1704 deg C for natural gas. Development of FBC technology, as a conventional coal combustion technology, is also included in this path.



52.1 **Japan's targets for advanced ultra-supercritical (A-USC) technology development**

**Ultra –Supercritical **Advanced Ultra-Supercritical*
Hitachi 2008

A continuation of IGCC development is the second technology-development path. As a result of increasing environmental concerns, near zero emissions (including CO_2) poses one of the biggest challenges to coal-fired power plants. As described in the previous section, it is easier to remove and capture CO_2 from pre-combusted, pressurised syngas with IGCC technology. Therefore, IGCC technology is deemed as a promising alternative to compete with pulverised coal technology, in terms of thermal efficiency and near zero emissions capability.

Currently, IGCC technology has a thermal efficiency of 40 percent and its capital cost exceeds about USD 1,300 per kilowatt, which is not competitive with pulverised coal technology. As such, the US Department of Energy (DOE) has established R&D programmes with efficiency targets for 2010 and 2020. By 2010, the goal is to increase efficiency to 50 percent (HHV), while reducing capital costs to about USD 1,000 per kilowatt, and by 2020 to increase efficiency to 60 percent with a capital cost of about USD 900 per kilowatt.

In terms of progress, these programmes are facing technical challenges. These include (1) the development of gas turbines to burn syngas (a low density fuel) and the (2) utilisation of fuel cell technology, as a hybrid system, so as to further improve efficiency.

Another project, FutureGen, is an advanced, zero-emissions IGCC plant that integrates carbon capture and storage (CCS) technology. This project, however, has recently faced cancellation.

The third technology-development path is to develop another near-zero emissions coal-based technology, where syngas is burned with oxygen instead of air to produce steam (supercritical with ultra high temperatures of 3100 deg F). The development of steam turbine material and cooling technology to sustain these extreme steam conditions are technical challenges.

TECHNOLOGY TRANSFER: CHINESE MODEL

The Chinese government is actively promoting technology development in the Chinese power sector and the construction of new power plants with advanced technology.

The targets for coal-fired power generation technology development are:

(1) To increase the domestic production ratio of supercritical and ultra-supercritical power generation units,

(2) To master design practices and manufacture ultra-supercritical power units by 2010, and

(3) To develop domestic design practices and manufacture ultra-supercritical power unit by 2020.

The targets for gas-fired power generation technology development are

(1) To master design practices and manufacture large to medium sized E and F-class gas turbines by 2010, and

(2) To develop domestic design practices and manufacture the world's most advanced gas turbines by 2010.

To foster domestic manufacturing capacity, Chinese manufactures have formed joint venture companies with foreign entities. As summarised in [53.1 and 54.1], China's three manufactures (Harbin Power Equipment Corporation, Shanghai Electric Group, and Dongfang Electric Corporation) are respectively teaming up with the world's leading manufactures.

	TECHNOLOGY COOPERATION WITH FOREIGN COMPANIES	POWER PROJECTS OUTSIDE CHINA
HARBIN POWER EQUIPMENT CORPORATION	TOSHIBA ELECTRIC COMPANY (JAPAN) ABB (SWEDEN) SIEMENS (GERMANY) GE (GENERAL ELECTRIC COMPANY) (UNITED STATES) CMI (COCKREILL MAINTENANCE & INGENIERIE) (BELGIUM) ALSTOM (FRANCE)	SUDAN BANGLADESH VIETNAM BRAZIL INDONESIA PAKISTAN PHILIPPINES
DONGFANG ELECTRIC CORPORATION	GE HYDRO VOTH ALSTOM HITACHI MITSUBISHI FOSTER WHEELER BABCOCK	VIETNAM INDIA INDONESIA PAKISTAN TURKEY IRAN

53.1 **Manufacturing companies of power generation equipment in China**

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These joint ventures, between Chinese and foreign manufactures, offer mutually beneficial outcomes. Through the transfer of technology by foreign companies, China's manufactures have expanded domestic capacity to produce power generation technologies, such as supercritical and ultra-supercritical. Currently, the reliability of Chinese-produced technologies only differs by 5 percent from those of foreign manufactures. Moreover, the per kilowatt cost of each power generation unit produced in China is substantially lower due to lower input costs.

	TECHNOLOGY COOPERATION WITH FOREIGN COMPANIES	POWER PROJECTS OUTSIDE CHINA
SHANGHAI ELECTRIC GROUP SHANGHAI ELECTRIC POWER GENERATION GROUP SHANGHAI POWER TRANSMISSION AND DISTRIBUTION CO., LTD SHANGHAI ELECTRIC HEAVY INDUSTRY GROUP	SIEMENS WESTINGHOUSE SIEMENS-WESTINGHOUSE POWER CORPORATION ALSTOM FOSTER WHEELER (USA) ABB AMERICAN POWER CONVERSION (APC) (USA) TOSHIBA MISTSUBISHI SCHNEIDER AREVA TRENCH PANASONIC FUJIKURA LTD	BANGLADESH THAILAND INDIA VIETNAM INDONESIA

54.1 **Manufacturing companies of power generation equipment in China**
APERC 2008

In fact, the combination of high reliability and low capital cost has helped these joint venture companies increase exports of their manufactured generation technologies. These gains are enjoyed by both the Chinese manufactures and their foreign partners.

IMPLICATIONS

Prospects for our potential technology future entail the development of more efficient, less polluting, and more cost competitive technology for both coal and natural gas-fired power generation. This can be achieved through further refinement and/or innovative hybridisation of existing technologies.

Though several factors can impact technology development, capital investment is the defining factor that determines the penetration of technology into the market. The best and most advanced technologies tend to be more expensive than current proven technologies and therefore it is difficult to replace existing technologies in the short-term. Because of cost, best-practice technologies, like supercritical pulverised coal fitted with flue gas desulphurisation (FGD) and NOx reduction equipment, are not fully deployed in some economies even though they are commercially proven. As such, it is important that R&D for next-generation technologies also advance innovations that can help reduce cost and be used with existing technologies. This may help best practice technologies gain greater market penetration.

In addition to R&D, technology transfer from developed to developing economies can help towards the diffusion of advanced technologies. Technology transfer can strengthen developing economies' capacity to manufacture advanced technology and lower the capital cost of generation technologies. In addition, foreign companies can expand their export market, so as to include the export of lower cost generation technologies to manufacturers in developing economies, by way of these joint venture companies. To realise such a win-win situation for both host economy and investors, policymakers in developing economies should create suitable conditions that can facilitate investment by foreign manufactures.

Collaboration among policymakers, industry, and academia (specifically in economies where a strong industry knowledge base and a strong power generation growth market already exist) is encouraged in order to accomplish these technological innovations.

ENERGY EFFICIENCY INVESTMENT IN THE POWER SECTOR: BARRIERS AND FACILITATORS

INTRODUCTION

Adoption of energy efficient power technologies, through refurbishment or total replacement, can bring substantial benefits to generators, as well as to society as a whole. Generators can reduce their energy procurement costs and potential emission fees (related to both local and global emissions reduction targets). Society may also directly enjoy benefits, such as air quality improvement, as a result of the introduction of energy efficient power generation technologies.

Despite these benefits, generators often choose less energy efficient technologies, due mainly to lower initial capital requirements. Under a deregulated market, in particular, power generators may place priority on merely determining how to supply electricity at a competitive retail price. Since cost recovery from an investment in energy efficient technologies generally takes place after ten years of operation, generators in a competitive market often select technologies with a lower initial capital investment. These technologies tend to be less energy efficient.

Regulation, on energy efficiency or the environment, is another factor that affects the choice of power generation technologies. For example, in rapidly developing APEC economies that lack regulations on energy efficiency, generators typically opt for technologies with lower initial capital requirements, regardless of long-term gains in energy and cost savings arising from energy efficient technologies.

This chapter explores barriers to the adoption of energy efficient power generation technologies. The analysis begins with a brief overview of investment barriers. This assessment is followed by a few cases of policies and measures that can help facilitate investment in energy efficient technologies.

BARRIERS TO INVESTMENT IN ENERGY EFFICIENT TECHNOLOGY

A number of factors can be identified as barriers to investment in energy efficient technologies. These may include (1) high initial capital cost, (2) lack of access to financing, (3) market deregulation, (4) absence of regulation, (5) inadequate enforcement mechanisms, (6) inappropriate domestic capacity to manufacture generation technologies, and (7) lack of information.

Out of numerous factors, this section evaluates the three main barriers to investment in energy efficient generation technologies. These barriers include:

- Company hurdle rates and a project's real rate of return,

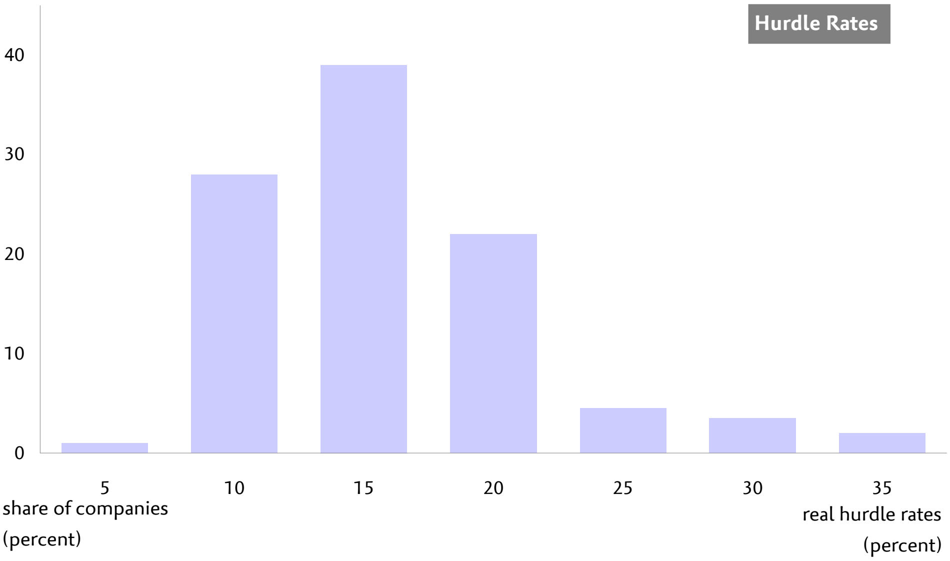
- Market deregulation and investment in the power sector, and
- Low electricity retail prices.

COMPANY HURDLE RATES AND A PROJECT'S REAL RATE OF RETURN

A company's hurdle rate is considered the benchmark for a project's financial feasibility. Since hurdle rates are often set higher than the rates of return from energy efficient power generation technology projects, these projects are not generally accepted despite potential energy and CO_2 emissions reduction savings. Therefore, understanding the level of hurdle rates and factors that affect them can be an important step towards promoting energy efficient power generation technologies.

The hurdle rate is a minimum rate of return that is set by a company. Most companies set the hurdle rate to reflect (1) a weighted average cost of capital and (2) project risks. Companies, in general, generate several hurdle rates and apply one of them depending on project type. For example, according to a survey conducted by Poterba and Summers (1995), the average difference between the highest and lowest hurdle rate is broad (11.2 percent).[a] The survey results indicated that strategic projects, such as entering new markets or defending low market share, have low hurdle rates.

What is the average hurdle rate used by companies? According to a recent survey conducted by Meier and Tarhan (2007), the average hurdle rate is 14.1 percent.[b] This represents the nominal level that the companies surveyed applied from 2001 and 2003. According to the Poterba and Summers' (1995) survey, the average hurdle rate was 12.2 percent, with a 2 percent inflation rate. If this inflation rate is applied, the former result by Meier and Tarhan almost corresponds with the latter one by Poterba and Summers (12.1 percent with inflation rate applied).



58.1 **Real hurdle rates: Surveyed result**

Poterba and Summers 1995

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[a] *This survey was given to CEO's of 228 US companies.*

[b] *This survey was given to CFO's of 127 US companies.*

Compared to a 12 percent hurdle rate, the rates of return from energy efficiency projects in power generation tend to be low.

To illustrate the expected rates of return for replacing a low thermal efficiency power generation unit with a higher efficiency unit, two hypothetical projects are modelled. The projects' analysed include the replacement of a coal-fired power generation unit with:

- a higher efficiency coal-fired generation unit[c] (*Case 1*) or
- a CCGT generation unit (*Case 2*).

The simulation exercise shows rather low prospects for the introduction of energy efficient power generation technologies. The estimated IRRs of *Case 1* and *Case 2* are 8.8 percent and 3.8 percent respectively, which are far below the average hurdle rate of 12 percent. Capital investment for these energy efficient technologies is higher than that for conventional units. In addition, electricity retail prices are often maintained low, for most developing economies, as well as some developed ones. Therefore, it is not easy for power generation replacement projects to obtain a high enough rate of return to cover the investment requirement.

CASE 1: COAL-FIRED POWER GENERATION					
INSTALLED CAPACITY	150*2 (MW)	FUEL PRICE	USD 1.7/GJ	ELECTRICITY PRICE	USD 0.046/KWH
CAPACITY FACTOR	70%	FUEL PRICE ESCALATION	0.80%	O&M COSTS	USD 0.016/KWH
PLANT EFFICIENCY	40%	CAPITAL INVESTMENT	USD 1,000/KW	**IRR**	**8.80%**

CASE 2: CCGT					
INSTALLED CAPACITY	150*2 (MW)	FUEL PRICE	USD 3/GJ	ELECTRICITY PRICE	USD 0.057/KWH
CAPACITY FACTOR	45%	FUEL PRICE ESCALATION	1.50%	O&M COSTS	USD 0.018/KWH
PLANT EFFICIENCY	45%	CAPITAL INVESTMENT	USD 700/KW	**IRR**	**3.80%**

59.1 **IRR estimation: Coal-fired power generation plant replacement**

MARKET LIBERALISATION AND INVESTMENT IN THE POWER SECTOR

Technology choice is affected by market structure. For example, under a liberalised market environment, whether competition is retail or wholesale, generators are essentially required to produce electricity at a relatively low cost compared with competitors. In such a market environment, advanced technologies are often outside of the generators' choice due to higher initial capital investment requirements.

Ownership structure can also explain an under-investment in energy efficient technologies. Private generation companies act based on

[c] *Ultra-supercritical technology is a high efficiency technology option.*

stockholder interests; therefore achieving higher returns becomes their primary goal. Despite substantial energy savings potential, introduction of advanced technologies can be burdensome to a company's balance sheet. High initial capital investment may not be easily recovered when the retail price of electricity needs to be maintained at a competitive level.

LOW ELECTRICITY RETAIL PRICES

Electricity retail prices may not reflect the true cost of generation. In some developing APEC economies, for example, electricity retail prices are often regulated either to maintain prices at an affordable level for residential customers or to protect industry customers through cross-subsidies. For example, the recent rise in input energy costs has not been directly reflected in the retail prices within some developing APEC economies in order to ensure affordability and control inflationary pressures.

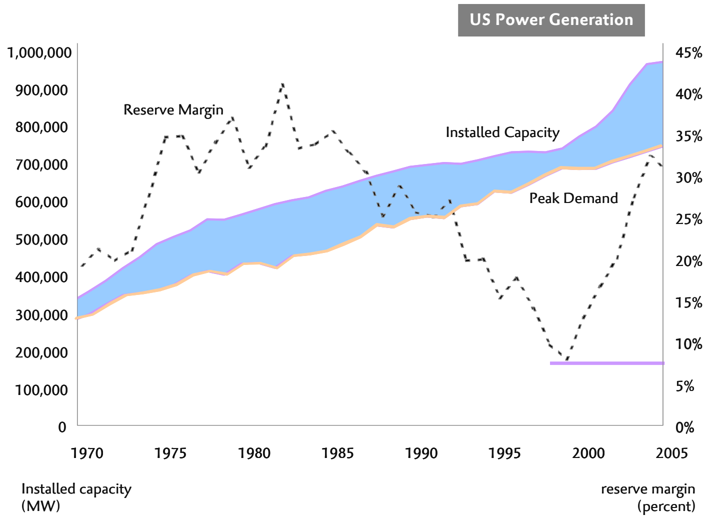
Furthermore, electricity prices do not incorporate environmental costs associated with fuel combustion. Negative externalities arising from electricity generation (related to local air quality or the global environment) are excluded from electricity retail prices, particularly in economies that do not enforce environmental regulations.

With low electricity retail prices, compared to the true cost of generation, generators have little incentive to invest in advanced technologies. Low electricity retail prices will not generate a high enough rate of return to cover the initial investment.

POWER MARKET LIBERALISATION: THE UNITED STATES

The United States offers an interesting example with respect to how market liberalisation can affect generators' investment decisions and technology choices. The United States has deregulated its wholesale power market and more than half its states have deregulated their retail power markets since the introduction of the Energy Policy Act of 1992 (EPACT). EPACT was the first major reform initiative taken by the United States to open access to transmission networks. The next major reform occurred in 1996 when the Federal Electricity Regulatory Commission (FERC) issued Order 888 and 889, which required utilities to unbundle generation from transmission services.

Until the early part of the 2000s, when the United States experienced large-scale blackouts in California and the Pacific Northwest region, the pressure to be competitive and reduce supply costs was widespread in the United States power market.

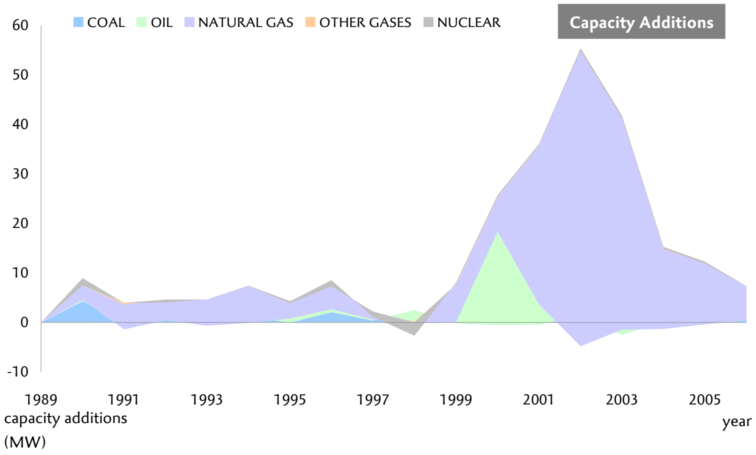


61.1 **Power generation in the United States: Installed capacity, peak demand, and reserve margin**

[61.1] shows historical trends of the US power sector's installed capacity, peak demand, and reserve margin. As the figure illustrates, limited capacity additions occurred after deregulation of the power sector in 1992. Faced with competitive pressure to reduce costs, utilities reduced new capacity additions. This resulted in a decrease in reserve margins from around 26 percent in 1992 to 8 percent in 1998. From 1998 onwards, however, reserve margins rebounded. This is largely attributable to an expansion in the deployment of CCGT units, as a result of reduced capital costs and greater concerns over supply reliability.

In addition to limited capacity additions, technology choice was also affected by deregulation in the electricity sector. [61.1] shows the historical trend of capacity additions in the US power sector from 1989 to 2006. Until the year 2000, capacity additions were maintained low regardless of energy type.

In terms of coal-fired power generation, during the observed years, only one unit of supercritical technology was constructed (in 1991), even though the United States has domestic manufacturing capacity. Despite substantial energy savings potential from supercritical technology, this technology was not used because of its higher capital investment requirement, compared to subcritical technology, and technological uncertainties.



62.1 **Power generation in the United States: Capacity additions by source**

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Ultimately, the example of the United States, although radical, offers an important lesson to economies that undergo or have plans to deregulate their power sectors. This case clearly highlights that regulators may need to provide generators with additional incentives to improve generation efficiency. For example, a higher wholesale electricity price could be provided if a generator improves generation efficiency.

In addition, providing long-term policy direction may help enhance generators' planning horizons. For example, an economy's commitment to reduce CO_2 emissions, through the UNFCCC framework, may facilitate generators in their efforts to apply energy efficient technologies.

POLICIES AND MEASURES TO FACILITATE INVESTMENT

The adoption of advanced technologies is not necessarily an attractive option for generators, especially when considering rates of return relative to capital investment requirements. This may be particularly true for economies that are deregulating their electricity sectors. Also, in developing APEC economies, generators cannot easily adopt advanced generation technologies due to a lack of financial sources. Appropriate financial incentives should be provided to generators in order to encourage a wider application of energy efficient power generation technologies.

Financial incentives, in the form of tax breaks, accelerated depreciation, and low interest rates, could be provided when generators apply advanced power generation technologies. A preferential pricing mechanism is another potential option. In this case, for example, regulators can benchmark wholesale prices based on plant efficiency levels.

Aside from the aforementioned incentives, this section considers three policies/measures that can help facilitate the adoption of energy efficient power generation technologies. These policies/ measures include:

- the Clean Development Mechanism (CDM),

[d] *Despite earlier expectations of a shift to CCGT, the US electricity sector is actually showing signs towards a shift back to coal-fired power generation. This shift is spurred by the rise in natural gas prices and reduced domestic production.*

- regional cooperation, and
- energy efficiency certificate trading schemes.

In APEC, CDM can become a useful tool to facilitate the transfer of energy efficient power generation technologies to developing economies. Investment for a CDM project comes from developed economies that ratified the Kyoto Protocol. This capital can assist in the deployment and installation of advanced technologies within a developing economy that may lack financial capacity.

Carbon credits generated from a CDM project can improve overall financial performance. To understand the magnitude, a simulation exercise that looks at a hypothetical power generation unit replacement project, with a 20 year project period, was conducted. In this exercise, a coal-fired power generation unit is replaced by a higher thermal efficiency unit rated at 40 percent. To understand how revenue from carbon credits could improve the financial performance, two baselines are considered:

- a low baseline at 25 percent thermal efficiency and
- a high baseline at 35 percent thermal efficiency.

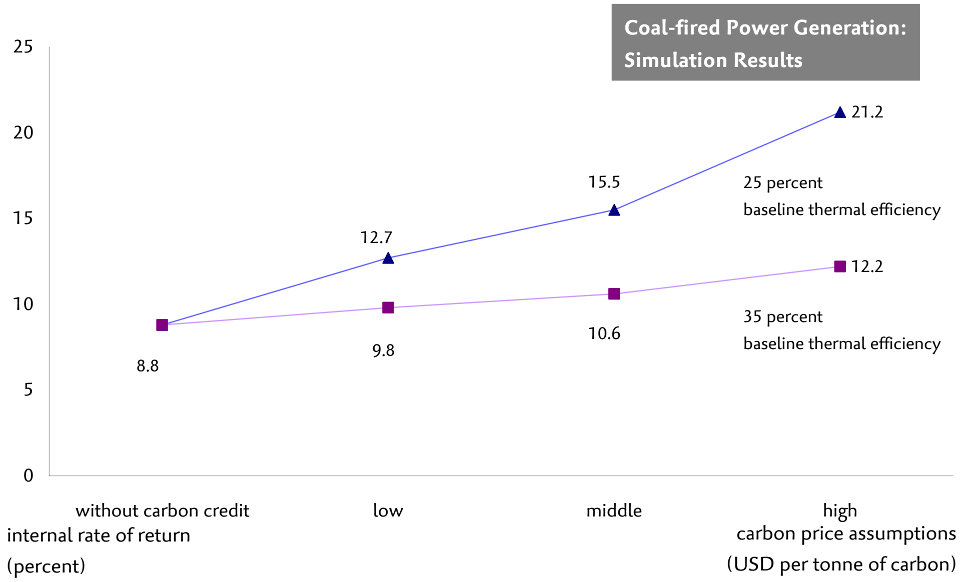
This means that the low baseline case can generate more carbon credits than the high baseline case. Both cases assume a 70 percent capacity utilisation factor.

The simulation exercise results are presented in [63.2]. The x-axis shows four carbon price assumptions (no carbon credit, low, middle, and high). The y-axis shows the corresponding IRR results.

To evaluate the influence of carbon price on a project's IRR, four cases are analysed:

- No carbon price case;
- Low carbon price case (USD 20 per tonne-C);
- Middle carbon price case (USD 26 per tonne-C, with a 5 percent annual escalation rate); and
- High carbon price case (USD 44 per tonne-C, with a 6 percent annual escalation rate).

63.1 **Carbon price assumptions**



63.2 **IRRs: Coal-fired power generation with different carbon price assumptions**

APERC 2008

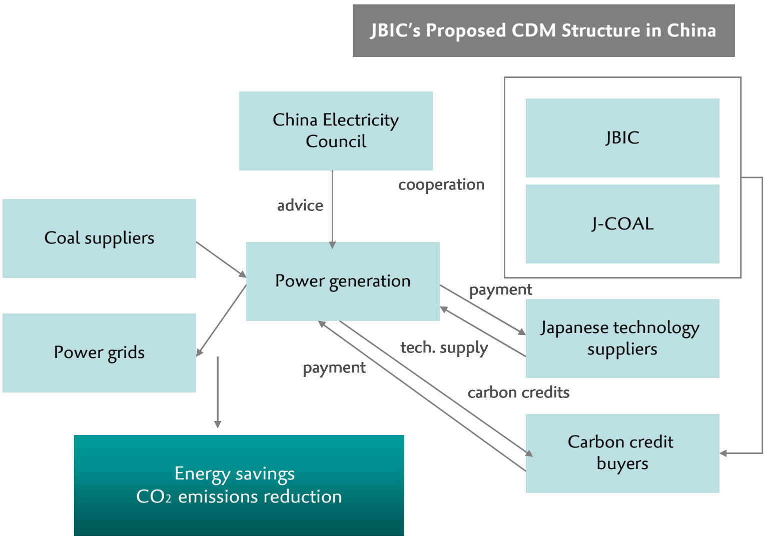
The simulation exercise clearly shows that earnings from carbon credits can improve the overall financial performance of a unit replacement project. Without carbon credits, this project may generate an IRR of 8.8 percent. In contrast, with the highest carbon price, the project may generate a maximum IRR of 21.2 percent.

REGIONAL COOPERATION TO ASSIST INVESTMENT IN THE POWER SECTOR

CDM has great potential to serve as an effective means to promote the adoption of advanced power generation technologies. By adding extra revenue from carbon credits, CDM can increase the financial viability of a power generation project using advanced technologies in rapidly developing economies.

In reality, however, there are only a limited number of CDM projects related to energy efficiency improvement in power generation. According to UNFCCC statistics, more than 1,091 CDM projects have been registered (as of early 2008). Energy projects, for both renewables and non-renewables, account for about half of the total registered CDM projects. Out of this, only 15 projects are related to energy efficiency improvements for power generation systems. This includes fuel switching from coal to natural gas, oil to natural gas, and cogeneration for industrial users.

To promote the use of CDM for power sector energy efficiency improvements in China, a proposal has been made by the Japan Bank of International Cooperation [64.1]. In the proposed scheme, China's Electricity Council, through cooperating with JBIC and J-Coal, is supposed to identify areas for energy efficiency improvement in the power sector. Subsequently, China's power generators are to purchase Japanese technologies to aid in this efficiency improvement. Carbon credits obtained from a project will then be sold to a joint fund established by JBIC and J-Coal.



64.1 **Proposed CDM structure for power sector efficiency improvements in China**

J-Coal 2007

The proposed scheme is based on a bilateral agreement between China and Japan to collaborate on energy efficiency improvements. The agreement was reached, in 2007, because it could bring mutually beneficial outcomes to both China and Japan. In China, the government established an objective to achieve a twenty percent energy intensity improvement target during its 11th five-year plan period (2006-2010). Thus, collaboration with Japan could bring technological know-how and financial assistance to help them achieve this target. At the same time, Japan needs to meet its Kyoto target for GHG emissions reduction (6 percent below 1990 levels) during the first commitment period (2008-2012). Compared to domestic alternatives, cooperation with China could provide Japan with lower cost CO_2 emissions reduction options.

It is important to note that China's support will reduce transaction costs for Japanese investors. Without China's support, Japanese investors may not find cost effective options because of transaction costs related to finding potential projects, gathering necessary information, communicating with central and local authorities, and going through a lengthy project approval process.

ENERGY EFFICIENCY CERTIFICATE TRADING SCHEME

Supply-side energy efficiency improvements may only fulfil part of the goal to reduce energy consumption. Supply-side focused measures, such as tax breaks and lower interest rates for the adoption of new technologies, could encourage generators to increase electricity generation (at a lower cost), thus, overall energy consumption might increase. To fully realise an energy efficiency improvement, a system should be established that encourages demand-side and supply-side efficiency measures.

A number of policies and measures have been implemented in APEC economies to encourage demand-side energy efficiency improvements.[e] One noteworthy policy measure, implemented in Australia, tries to integrate generators in the process to increase demand side efficiency.

In 2003, New South Wales (NSW), Australia implemented the world's first energy efficiency credit (or white certificates) trading programme. The scheme is part of the NSW Greenhouse Gas Abatement Scheme (GGAS), which commenced in January 2003. The NSW Greenhouse Gas Abatement Scheme requires electricity retailers and other parties to meet mandatory targets for reducing greenhouse gas emissions associated with electricity generation and consumption.

The NSW Government has set an annual target to reduce per capita CO_2 emissions from 8.65 tonnes in 2003 to 7.27 tonnes in 2007. The scheme's participants, called benchmark participants, are given annual benchmark greenhouse gas emissions reduction targets based on their size of electricity supply and demand [65.1].

As part of the scheme, New South Wales Greenhouse Abatement Certificates (NGACs) can be freely traded among benchmark participants. For example, a benchmark participant can purchase

The parties required to meet the targets include:

- Electricity retailers,
- Electricity customers taking supply directly from the Australian National Electricity Market,
- Electricity generators with contracts to supply electricity directly to customers and large-volume customers.

65.1 **Parties required to participate in GGAS**
David Crossley 2005

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[e] *These include DSM schemes and ESCOs.*

NGACs can be generated from the following activities:

- Emissions reduction from electricity generation,
- Reduction of electricity consumption,
- Carbon sequestration, and
- Industrial activities to reduce on-site greenhouse gas emissions (excluding electricity consumption).

66.1 **Activities that generate NGACs**

NGACs from other parties if they cannot meet the greenhouse gas reduction target [66.1].

From 2003 to 2006, the scheme allowed benchmark participants to rollover up to 10 percent of their unmet target to the following year without paying a penalty. It was mandatory for this rollover amount to be abated in the following year. In order to meet the emissions target of 7.27 tonnes of CO_2 per capita, the scheme removed the rollover feature in 2007.

Currently, an expansion of the scheme, to include all of Australia, is under consideration. The outcomes from 2007, as of July 2008, have not been revealed; however, the Scheme could serve as a useful tool for Australia to meet its Kyoto target through integrating generators and consumers in its efforts to reduce energy consumption and CO_2 emissions.

IMPLICATIONS

Generators may encounter a number of barriers to install energy efficient power generation technologies. These barriers may include high initial investment requirements, lack of access to financing, market deregulation, absence of regulation, and low electricity retail prices.

Under a deregulated market environment, in particular, generators may choose lower cost technologies that are not necessarily energy efficient options. Financial incentives are necessary to promote the wider adoption of energy efficient generation technologies. In addition, policy should be established to allow long-term corporate planning. Even under a deregulated market environment, long-term policy goals or regulation, on energy and the environment, may lead to long-term corporate planning that can aid generators in their efforts to improve generation efficiency.

Solely supply-side focused energy efficiency improvement measures, such as tax breaks and lower interest rates, may increase electricity generation (at a lower cost), thus, increasing overall energy consumption. To fully realise energy efficiency improvement potential, demand-side measures should be integrated with supply-side measures. For example, regulation could require generators to improve demand-side energy efficiency.

For developing economies, CDM could play a critical role towards the wider application of energy efficient power generation technologies. CDM could increase the financial viability of a project to install energy efficient technology through the sales of carbon credits. Currently, however, there are only a limited number of CDM projects related to power generation energy efficiency improvements. A mechanism should be created to balance the needs of host economies with that of investing economies, through bilateral or multilateral agreements among governments.

APEC economies can help each other identify areas for power generation energy efficiency improvement and facilitate investment. Such cooperation could be realised through a strong commitment by member governments. With resilient government support, a regional energy efficiency fund could be created to help attain an APEC-wide energy efficiency improvement.

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I

METHODOLOGY:

ENERGY EFFICIENCY CALCULATIONS

DATA SOURCES

Historical data, prior to 2005, for energy inputs, electricity outputs, system losses, and electricity demand by sector is drawn from the IEA database. Due to historical data limitations, electricity data for Russia starts from 1990 and Papua New Guinea's energy data starts from 1980, as a combination of both EGEDA and EIA database data.[a] In addition, data on installed generation capacity is obtained from the Energy International Administration's (EIA), International Energy Annual 2005.

Macro-economic data (GDP, population, income, share of Services and Industry sectors to GDP) prior to 2002 is drawn from Global Insight Data and post 2002 is projected from the World Bank's World Development Indicators 2007 and some national statistics. Data related to household characteristics is obtained from national statistics.

METHODOLOGY

DECOMPOSITION ANALYSIS: PRIMARY ENERGY DEMAND GROWTH IN THE POWER SECTOR

Primary energy demand for power generation in year *t*, PED_t, is the sum of energy demand from each energy input, PED_{it}:

$$PED_t = \sum_i PED_{it}$$

where *i* is the index of energy inputs.

The total primary energy demand, PED_t, is a function of three variables in year *t*:

I. Power Generation, G_t, measures the activity effect. It takes into account the generation from each energy input

$$G_t = \sum_i G_{it}$$

II. Energy Efficiency of energy input, EE_{it}, measures energy conversion efficiency. It is defined as the primary energy demand (PED_{it}) per unit of power generation (G_{it})

$$EE_{it} = PED_{it} / G_{it}$$

III. Generation Mix, S_{it}, measures the generation mix effect. It indicates the share of power generation that energy input *i* contributes to total power generation,

$$S_{it} = G_{it} / G_t$$

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[a] *Due to a lack of electricity generation data for PNG and the fact that less than 1 percent of power generation comes from natural gas, the average oil-fired efficiency is estimated by using the fuel inputs and generation from both oil and natural gas.*

The following equation represents the total primary energy demand in terms of power generation, energy efficiency, and generation mix:

$$PE_t = \sum_i (G_t \times EE_{it} \times S_{it}) = \sum_i (G_t \times [PE_{it}/ G_{it}] \times [G_{it}/ G_t])$$

The Laspeyres indices and Divisia parametric approaches are used to measure the relative impact of each term over time. In the decomposition analysis, changes in primary energy demand, between the base year and year t, can be divided into power generation, energy efficiency, generation mix effects, and a residual term:

$$\begin{aligned}
\Delta PED_{0t} &= PED_t - PED_0 \\
&= \sum_i ([G_0 + \Delta G_t] \times [EE_{i0} + \Delta EE_{it}] \times [S_{i0} + \Delta S_{it}]) - \sum_i (G_t \times EE_{i0} \times S_{i0}) \\
&= \sum_i (\Delta G_t \times EE_{i0} \times S_{i0}) && \leftarrow \text{power generation effect} \\
&+ \sum_i (G_0 \times \Delta EE_{it} \times S_{i0}) && \leftarrow \text{energy efficiency effect} \\
&+ \sum_i (G_0 \times EE_{i0} \times \Delta S_{it}) && \leftarrow \text{generation mix effect} \\
&+ R_{0t} && \leftarrow \text{residual term}
\end{aligned}$$

where

PED_t, PED_0 primary energy demand of energy input in year *t* and *0* (base year),

$G_0 + \Delta G_t$, G_0 power generation in year *t* and *0*,

$EE_{i0} + \Delta EE_{it}$, EE_{i0} energy efficiency of energy input *i* in year *t* and 0,

$S_{i0} + \Delta S_{it}$, S_{i0} share of energy input *i* in year *t* and *0*.

THERMAL EFFICIENCY OF POWER GENERATION

The thermal efficiency of power generation is calculated based on formula (IV). This formula was originally published in the *Handbook of International Comparisons of Energy Efficiency in the Manufacturing Industry*.[b]

$$E = (P + H \times s) / I \qquad \text{(IV)}$$

where

E	energy efficiency of power generation,
P	power production from public power plants and public CHP plants,
H	the heat output from public CHP plants,
s	0.175, correction factor between heat and electricity, defined as the reduction in electricity production per unit of heat extracted,
I	energy input for public power plants and public CHP plants

[b] *Graus et al. 2007*

BENCHMARK INDICATOR ON THE SYSTEM LOSSES

The benchmark indicator estimates the difference between each economy's system losses (T&D or operational own use losses) and APEC's overall average system losses. First, the T&D losses or operational own use losses are obtained. This is calculated as a ratio of electricity consumed (in the transmission and distribution sectors or in the operation of the power plant) to total electricity generation.

The final benchmark indicator is calculated by dividing APEC's total system losses (in a given year) by its total electricity generation in the same year. In short, the benchmark indicator is the weighted average of the region's system losses (T&D or operational own use) over the total electricity generation in a given year.

This is shown in the following formula (V):

$$BI_{APECj} = \sum SL_{ij} / \sum EG_{ij} \qquad (V)$$

where

BI_{APECj} benchmark indicator for APEC in year *j*

(j = 1985,…, 2005),

SL_{ij} system losses (T&D losses or operational own use) for economy *i* (*i* = each APEC economy) in year *j*,

EG_{ij} total electricity generation for economy *i* in year *j*.

II

GENERATION GROWTH AND POWER PLANT CHARACTERISTICS

INSTALLED CAPACITY – BY SIZE AND BY AGE DISTRIBUTION

In 2005, the United States, Japan, and Canada topped the list of APEC economies with the highest electricity generating capacity at 1,067 GW, 219 GW and 121.5 GW, respectively.[a]

By size classification, power plants ranging from 601 to 1000 MW comprise the largest share, 18.1 percent (309.8 GW), of generating capacity in the region. Power plants above 1000 MW hold the second largest majority share with 307.4 GW or 17.9 percent. Power plants ranging from 100 MW and below and 101 to 200 MW also contribute significantly to the region's total generating capacity, with 17.4 percent (297.4 GW) and 17.2 percent (294 GW), respectively. The remaining capacity is distributed between power plants ranging from 201 to 400 MW (284.7 GW or 16.6 percent) and 401 to 600 MW (221.2 GW or 12.9 percent).

	≤ 100 MW	101 - 200 MW	201 - 400 MW	401 - 600 MW	601 - 1000 MW	≥ 1000 MW	TOTAL
AUS	5764	4215	4215	6058	7082	22140	49473
BD	754	0	0	0	0	0	754
CDA	13503	10276	10307	5902	16957	64509	121454
CHL	2249	2220	5287	967	1283	0	12006
HKC	0	0	665	555	0	8796	10016
INA	3669	4033	5841	1407	3996	7870	26815
JPN	2047	8947	37800	47923	63556	58777	219050
ROK	1696	1086	2313	6057	2500	48606	62258
MAS	1169	1965	2094	2212	9675	5952	23067
MEX	8435	11397	19641	5915	2348	3292	51029
NZ	1823	1127	2868	972	1715	0	8505
RP	3299	1689	5049	1601	1905	2260	15803
PNG	303	0	0	0	0	0	303
CT	173	1807	7311	16222	8111	1602	35226
USA	251666	244219	179058	122984	188531	80553	1067010
VN	863	1036	2293	2386	2160	3010	11748
TOTAL	297414	294017	284740	221161	309818	307366	1714517

83.1 **Size distribution of power plants**

APERC 2008

In terms of age, New Zealand, Canada, and the United States have the largest share of generating capacities older than 40 years. These capacities, in addition to those 20 to 39 years old (756.8 GW), may either be replaced, refurbished, or retrofitted in the near term to improve current efficiency levels.

Southeast Asian economies (Viet Nam, Malaysia, and the Philippines) tend to have a larger share of new (less than 10 years) generation. [b]

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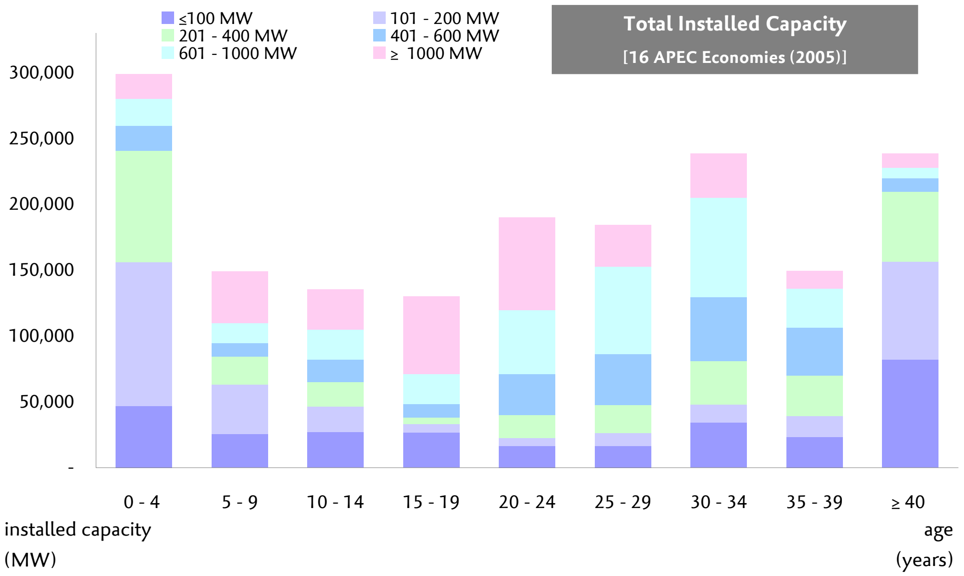
[a] *Based on available electricity generating capacity data (2005 data) for sixteen APEC economies. These economies include Australia, Brunei, Canada, Chile, Hong Kong, Indonesia, Japan, Korea, Malaysia, Mexico, New Zealand, the Philippines, Papua New Guinea, Chinese Taipei, the United States, and Viet Nam.*

[b] *After recovery from the 1997 Asian Financial Crisis, which affected economic growth in most Asian economies, many economies began to invest in new generation capacity.*

	0 - 4 YEARS	5 - 9 YEARS	10 - 14 YEARS	15 - 19 YEARS	20 - 24 YEARS	25 - 29 YEARS	30 - 34 YEARS	35 - 39 YEARS	≥ 40 YEARS	TOTAL
AUS	5673	3758	4798	1182	11475	6827	5936	4598	5226	49473
BD	99	57	377	158	15	0	40	6	2	754
CDA	8832	3681	10395	10042	14942	16893	13833	15132	27705	121454
CHL	2109	4676	1352	422	991	138	443	560	1315	12006
HKC	365	2188	300	2708	3900	555	0	0	0	10016
INA	337	2292	5223	1742	9956	1783	2714	0	2769	26815
JPN	22022	31914	30367	19909	29334	27071	35136	17137	6161	219050
ROK	5420	11111	10785	12488	10223	6492	1674	3784	283	62258
MAS	7899	9564	4908	0	696	0	0	0	0	23067
MEX	15633	3879	8111	4508	6127	5991	2974	1659	2148	51029
NZ	328	1368	486	1010	437	936	1037	836	2067	8505
RP	2850	5397	3139	367	2132	867	0	266	786	15803
PNG	1	38	1	74	52	27	67	34	8	303
CT	6720	7414	5856	830	6922	3536	2144	1280	523	35226
USA	216328	58729	47972	72744	92387	113216	172310	103871	189453	1067010
VN	4327	3087	1291	1920	440	100	138	285	160	11748
TOTAL	298942	149152	135362	130103	190029	184430	238445	149448	238606	1714517

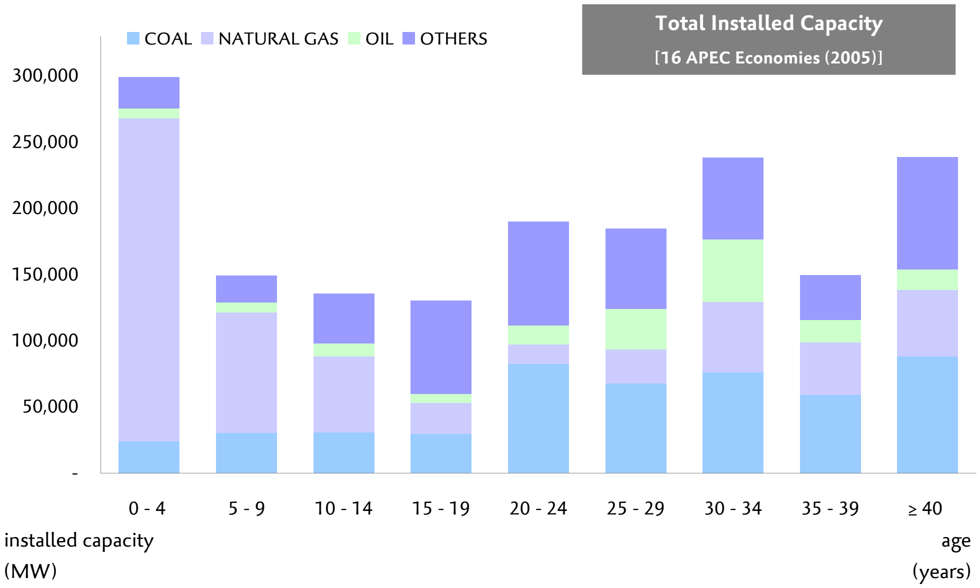
84.1 **Age distribution of power plants**

APERC 2008



84.2 **Age distribution of power plants by size**

APERC 2008



85.1 **Age distribution of power plants by energy-type**

APERC 2008

COAL-FIRED: SIZE AND AGE DISTRIBUTION

Coal is a key feedstock for power generation in the APEC region. As of 2005, a total of 488.8 GW of capacity is coal-based. Of this amount, the majority of power plants (161.3 GW or 33 percent) are between 601 and 1000 MW, while only about 5.2 percent (25.3 GW) are 100 MW and below.

In terms of the share that coal contributes to the total installed capacity mix, Hong Kong, Australia, and Malaysia have the highest percentage (66 percent, 61.2 percent, and 40.8 percent, respectively). This means that coal is the preferred feedstock in these economies. In absolute terms, however, the United States, Japan, and Australia are the top three economies with the highest coal-fired power plant capacity (336.8 GW, 38 GW, and 30.3 GW, respectively).

	≤ 100 MW	101 - 200 MW	201 - 400 MW	401 - 600 MW	601 - 1000 MW	≥ 1000 MW	TOTAL
AUS	228	820	1195	2073	5332	20640	30288
BD	0	0	0	0	0	0	0
CDA	159	306	1451	480	4334	9285	16014
CHL	242	1160	642	0	0	0	2043
HKC	0	0	0	0	0	6608	6608
INA	25	251	1324	0	800	5850	8250
JPN	465	3498	4759	7200	19930	2100	37952
ROK	252	0	1125	500	0	16340	18217
MAS	0	200	600	1000	5600	2021	9421
MEX	0	0	4700	0	0	0	4700
NZ	0	0	0	0	960	0	960
RP	198	210	1964	511	1294	0	4177
PNG	0	0	0	0	0	0	0
CT	75	325	1200	8850	1297	0	11747
USA	23657	44500	54059	77567	121791	15136	336708
VN	300	255	0	1040	0	0	1595
TOTAL	25599	51525	73018	99221	161337	77980	488680

86.1 **Size distribution of coal-fired power plants**

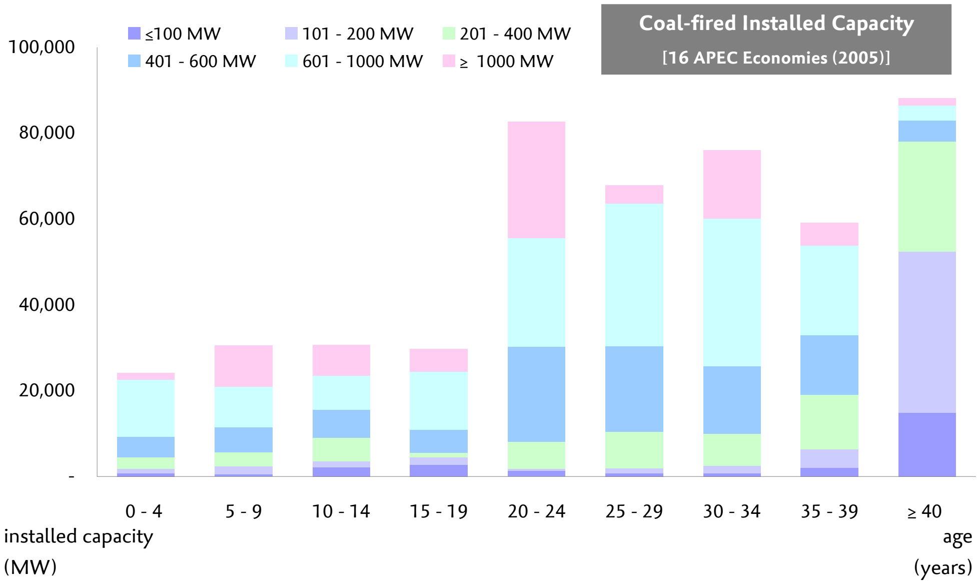
APERC 2008

By age structure, the majority of coal-fired power plants in the region, approximately 18.1 percent (88.1 GW), are classified as very old (40 years and over). In total, around 76.6 percent (373.7 GW) of the region's coal-fired capacity is older than 20 years. In the United States alone, 24.9 percent (83.6 GW) of the coal-fired power plant capacity is already older than 40 years.

	0 - 4 YEARS	5 - 9 YEARS	10 - 14 YEARS	15 - 19 YEARS	20 - 24 YEARS	25 - 29 YEARS	30 - 34 YEARS	35 - 39 YEARS	≥ 40 YEARS	TOTAL
AUS	2994	639	3720	700	10505	4000	3543	2140	2048	30288
BD	0	0	0	0	0	0	0	0	0	0
CDA	0	0	785	2065	1325	1230	4146	5528	936	16014
CHL	0	640	440	259	171	0	0	125	409	2043
HKC	0	0	0	2708	3900	0	0	0	0	6608
INA	0	0	800	0	6250	924	251	0	25	8250
JPN	9697	9136	7312	3012	3625	1175	1256	1802	937	37952
ROK	1600	5900	3116	536	6240	0	825	0	0	18217
MAS	5100	4121	200	0	0	0	0	0	0	9421
MEX	0	350	3150	300	900	0	0	0	0	4700
NZ	0	0	0	960	0	0	0	0	0	960
RP	210	3169	389	57	353	0	0	0	0	4177
PNG	0	0	0	0	0	0	0	0	0	0
CT	1847	4000	2200	550	1550		300	1100	200	11747
USA	1707	2600	8469	18567	47389	60421	65604	48364	83587	336708
VN	950	0	0	0	440	100	105	0	0	1595
TOTAL	24105	30555	30581	29713	82648	67850	76029	59059	88141	488680

86.2 **Age distribution of coal-fired power plants**

APERC 2008



87.1 **Age distribution of coal-fired power plants by size**

APERC 2008

NATURAL GAS-FIRED: SIZE AND AGE DISTRIBUTION

Based on available information, the most popular natural gas-fired power plant size is from below 100 MW to 400 MW. Power plants of 101 to 200 MW have the highest installed capacity (29.6 percent, 177.6 GW), followed by plants sized at 100 MW and below (22.8 percent, 136.4 GW) and 201 to 400 MW (22.3 percent, 133.6 GW).

Overall, the aggregate generating capacity of power plants sized at 200 MW and below equals 314 GW or 52.4 percent of the total natural gas-fired generating capacity. This amount indicates a huge potential for energy efficiency improvement, related to economies of scale, in putting up medium-to-large sized power plants in the future.

Fact 1:
Six APEC economies have more than 40 percent of their natural gas-fired power plant capacity in the 0 to 4 years age category. These economies include Mexico (70.2 percent), Viet Nam (70 percent), the Philippines (61.5 percent), the United States (46.3 percent), Chinese Taipei (41.1 percent), and Canada (40.9 percent).

Fact 2:
The majority of natural gas-fired power plant capacity between 5 to 9 years can be found in Hong Kong (100 percent), New Zealand (72.4 percent), Chile (69.6 percent), Australia (28.8 percent), and Japan (22.2 percent).

87.2 **Natural gas-fired power generation: Regional facts**

APERC 2008

	≤ 100 MW	101 - 200 MW	201 - 400 MW	401 - 600 MW	601 - 1000 MW	≥ 1000 MW	TOTAL
AUS	2077	2586	1329	2503	800	0	9294
BD	740	0	0	0	0	0	740
CDA	4329	2841	2145	0	950	0	10264
CHL	176	348	3195	0	643	0	4361
HKC	0	0	0	0	0	2188	2188
INA	220	685	2404	987	818	1012	6126
JPN	129	1715	9667	13385	19179	15900	59975
ROK	178	127	388	2910	1800	11350	16752
MAS	582	1765	894	1212	4075	2021	10549
MEX	3554	2240	2813	5915	983	3292	18797
NZ	261	125	1040	0	0	0	1426
RP	3	0	0	500	0	2260	2763
PNG	0	0	0	0	0	0	0
CT	0	864	4767	5372	670	0	11672
USA	124103	164354	104556	29325	16768	1027	440133
VN	0	0	384	1346	1440	1090	4260
TOTAL	136351	177649	133580	63454	48126	40140	599300

88.1 **Size distribution of natural gas-fired power plants**

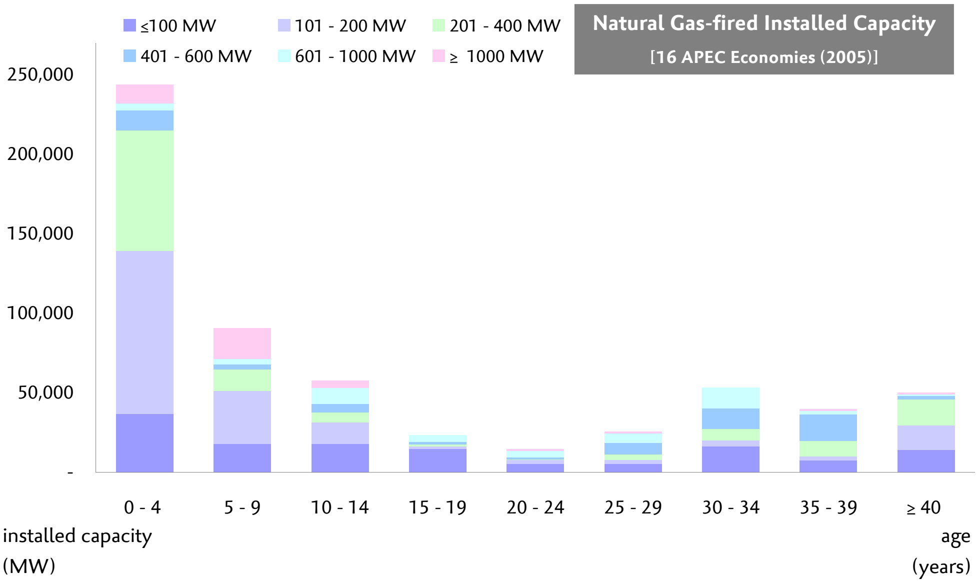
APERC 2008

In terms of age, more than half, 55.8 percent (334.7 GW), of natural gas-fired power plant capacity is relatively new, that is, below 10 years old. In fact, the majority of this capacity, 40.7 percent (243.7 GW), is 0 to 4 years old. In the early part of the 1990's, a shift to natural gas-fired power generation occurred as a result of reduced capital investment requirements and the relatively cheap price of natural gas. This trend may drastically change as natural gas fuel prices increase.

	0 - 4 YEARS	5 - 9 YEARS	10 - 14 YEARS	15 - 19 YEARS	20 - 24 YEARS	25 - 29 YEARS	30 - 34 YEARS	35 - 39 YEARS	≥ 40 YEARS	TOTAL
AUS	1675	2675	823	201	195	1759	551	554	862	9294
BD	99	57	364	158	15	0	40	6	2	740
CDA	4203	2252	985	300	158	499	297	119	1452	10264
CHL	1222	3033	38	0	0	0	0	0	68	4361
HKC	0	2188	0	0	0	0	0	0	0	2188
INA	0	920	3268	400	1018	0	300	0	220	6126
JPN	4998	13321	7021	5585	4690	7375	7290	6665	3030	59975
ROK	2857	4326	6780	21	30	1200	0	1538	0	16752
MAS	2152	3435	4602	0	360	0	0	0	0	10549
MEX	13187	1712	220	68	1383	428	1086	340	374	18797
NZ	40	1032	54	0	0	300	0	0	0	1426
RP	1700	1060	3	0	0	0	0	0	0	2763
PNG	0	0	0	0	0	0	0	0	0	0
CT	4793	3281	2054	280		764	500			11672
USA	203841	50741	31132	16487	6673	13286	43206	30543	44224	440133
VN	2980	896	384	0	0	0	0	0	0	4260
TOTAL	243747	90929	57727	23499	14522	25610	53270	39764	50233	599300

88.2 **Age distribution of natural gas–fired power plants**

APERC 2008



89.1 **Age distribution of natural gas-fired power plants by size**

APERC 2008

OIL-FIRED: SIZE AND AGE DISTRIBUTION

In 2005, 9.2 percent (157.1 GW) of the region's total generating capacity came from oil-fired generation. The prevalent power plant size range for this energy-type is 100 MW and below (25.9 percent, 40.7 GW), followed by 201 to 400 MW (25.7 percent, 40.4 GW), and 401 to 600 MW (21.1 percent, 33.1 GW).

Papua New Guinea and Indonesia are major users of oil for power generation, with shares of 46.6 percent and 32.7 percent, respectively. A significant share of oil-fired generating capacity, more than 20 percent each, can also be observed in Mexico, the Philippines, and Japan.

	≤ 100 MW	101 - 200 MW	201 - 400 MW	401 - 600 MW	601 - 1000 MW	≥ 1000 MW	TOTAL
AUS	597	105	304	0	0	0	1006
BD	14	0	0	0	0	0	14
CDA	934	718	1150	1518	0	3150	7470
CHL	721	0	0	0	0	0	721
HKC	0	0	665	555	0	0	1220
INA	2440	2364	1863	0	1678	0	8345
JPN	1294	3197	19746	17250	4100	0	45588
ROK	455	430	400	529	0	3200	5013
MAS	310	0	600	0	0	0	910
MEX	1997	4185	7596	0	0	0	13778
NZ	0	155	0	0	0	0	155
RP	1241	576	1195	590	0	0	3602
PNG	141	0	0	0	0	0	141
CT	0	0	750	2000	0	0	2750
USA	30650	6991	5732	8769	11886	0	64028
VN	183	295	716	0	0	0	1194
TOTAL	40977	19017	40717	31210	17664	6350	155936

89.2 **Size distribution of oil-fired power plants**

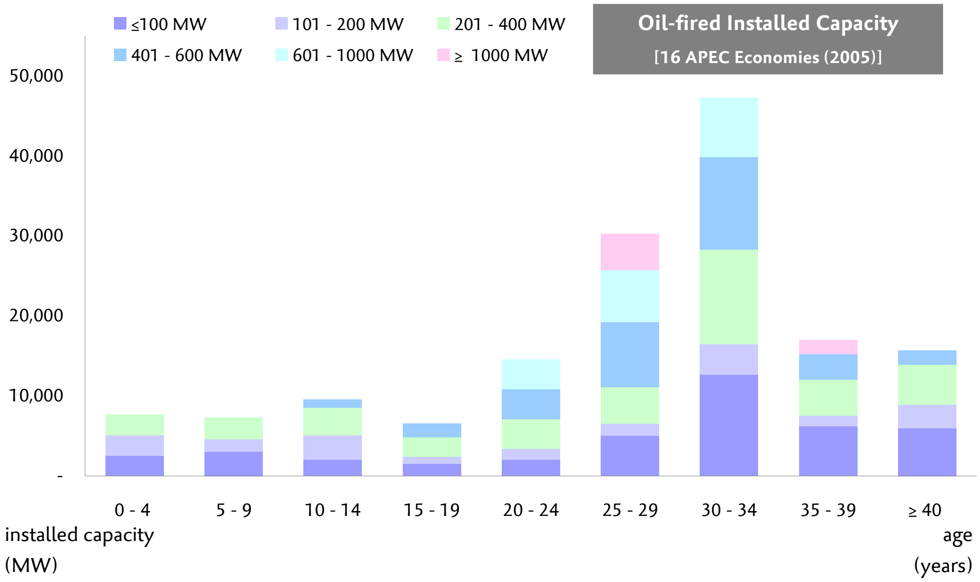
APERC 2008

As for the age structure of oil-fired generation, 80.1 percent (124.5 GW) is older than 20 years. In contrast, only about 9.6 percent (14.9 GW) is considered new or below 10 years old.

	0 - 4 YEARS	5 - 9 YEARS	10 - 14 YEARS	15 - 19 YEARS	20 - 24 YEARS	25 - 29 YEARS	30 - 34 YEARS	35 - 39 YEARS	≥ 40 YEARS	TOTAL
AUS	96	364	0	50	116	141	136	31	72	1006
BD	0	0	14	0	0	0	0	0	0	14
CDA	59	80	1014	142	38	3877	195	920	1147	7470
CHL	133	99	29	19	30	138	43	75	157	721
HKC	365	0	300	0	0	555	0	0	0	1220
INA	337	1370	476	25	1919	608	1886	0	1723	8345
JPN	1747	1033	393	2553	7000	6733	19675	5104	1350	45588
ROK	81	333	123	12	162	1575	529	2200	0	5013
MAS	600	98	86	0	126	0	0	0	0	910
MEX	596	1000	2498	2005	2674	3673	973	240	120	13778
NZ	155	0	0	0	0	0	0	0	0	155
RP	10	383	2359	310	101	98	0	20	322	3602
PNG	1	38	1	29	40	16	9	4	3	141
CT					500	1500	750			2750
USA	3518	1988	1801	1421	1887	11341	23067	8239	10766	64028
VN	0	525	471	0	0	0	33	165	0	1194
TOTAL	7699	7311	9563	6564	14592	30254	47296	16998	15659	155936

90.1 **Age distribution of oil–fired power plants**

APERC 2008



90.2 **Age distribution of oil-fired power plants by size**

APERC 2008

NON-FOSSIL FUEL: SIZE AND AGE DISTRIBUTION

Non-fossil fuel generating capacity includes hydropower, geothermal, solar, wind, biomass, waste, and nuclear. The aggregate capacity from these feedstocks totalled 469.2 GW, approximately 27.4 percent of the region’s total generating capacity in 2005. Thirty-nine percent of this capacity is above 1000 MW in size, which can be attributed to the prevalence of big nuclear power plants in some APEC economies (Japan, Korea, and the United States). Contrary to this, however, about 20.3 percent of non-fossil fuel generating capacity is below 100 MW, which legitimises the immense availability of renewable energy for small-scale power application.

Canada, New Zealand, Papua New Guinea, Chile, Japan, Korea and the Philippines rely heavily on non-fossil based energy for their electricity generation requirements. In the case of Canada and New Zealand, more than 70 percent of their electricity generating capacity is non-fossil fuel based. Japan and Korea have a non-fossil fuel based generation capacity of approximately 34 percent each, while Papua New Guinea and the Philippines have 53.4 percent and 33.3 percent, respectively.

	≤ 100 MW	101 - 200 MW	201 - 400 MW	401 - 600 MW	601 - 1000 MW	≥ 1000 MW	TOTAL
AUS	2862	704	1387	1482	950	1500	8885
BD	0	0	0	0	0	0	0
CDA	8082	6410	5561	3904	11674	52074	87705
CHL	1111	712	1450	967	640	0	4880
HKC	0	0	0	0	0	0	0
INA	984	732	250	420	700	1008	4095
JPN	159	537	3628	10088	20347	40777	75536
ROK	812	529	400	2119	700	17716	22276
MAS	277	0	0	0	0	1911	2188
MEX	2884	4972	4532	0	1365	0	13753
NZ	1562	847	1828	972	755	0	5964
RP	1858	903	1890	0	611	0	5261
PNG	162	0	0	0	0	0	162
CT	98	618	594	0	6144	1602	9056
USA	73255	28375	14711	7324	38086	64390	226141
VN	380	486	1193	0	720	1920	4699
TOTAL	94486	45826	37424	27276	82692	182897	470601

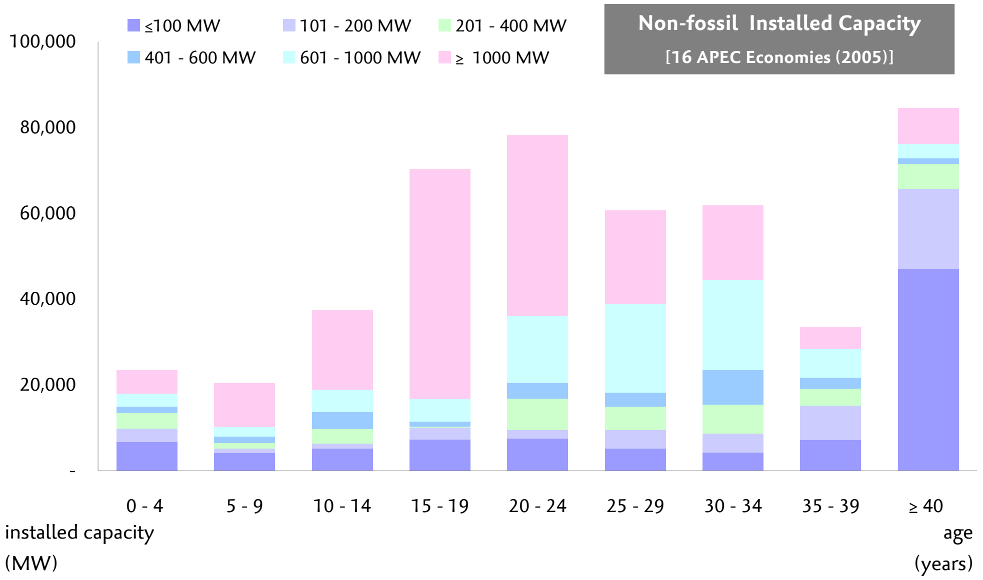
91.1 **Size distribution of non-fossil fuel power plants**

APERC 2008

	0 - 4 YEARS	5 - 9 YEARS	10 - 14 YEARS	15 - 19 YEARS	20 - 24 YEARS	25 - 29 YEARS	30 - 34 YEARS	35 - 39 YEARS	≥ 40 YEARS	TOTAL
AUS	908	81	255	231	660	927	1707	1873	2244	8885
BD	0	0	0	0	0	0	0	0	0	0
CDA	4570	1348	7612	7536	13421	11287	9195	8566	24171	87705
CHL	754	904	846	145	790	0	400	360	682	4880
HKC	0	0	0	0	0	0	0	0	0	0
INA	0	2	679	1317	769	251	277	0	800	4095
JPN	5580	8424	15641	8759	14019	11788	6915	3566	844	75536
ROK	881	551	766	11920	3791	3717	320	46	283	22276
MAS	47	1911	20	0	210	0	0	0	0	2188
MEX	1851	817	2243	2135	1170	1890	915	1079	1653	13753
NZ	133	336	432	50	437	636	1037	836	2067	5964
RP	930	784	388	0	1679	769	0	246	464	5261
PNG	0	0	0	45	12	11	59	30	6	162
CT	80	133	1602		4872	1272	594	180	323	9056
USA	7261	3399	6570	36269	36438	28169	40433	16725	50876	226141
VN	397	1666	436	1920	0	0	0	120	160	4699
TOTAL	23391	20357	37491	70327	78267	60717	61851	33628	84573	470601

92.1 **Age distribution of non-fossil fuel power plants**

APERC 2008



92.2 **Age distribution of non-fossil fuel power plants by size**

APERC 2008

III

METHODOLOGY:

POWER GENERATION LEEI INDEX

The Power Generation LEEI index was designed to identify fundamental driving factors that contribute to increasing an economy's likelihood to improve efficiency within the power generation sector. It can serve as a tool to gauge an economy's potential for power generation investment.

The strength of this index comes from its ability to discern the soundness of energy efficiency investment within a given generation portfolio. To effectively determine potential investment strategies, it is important to differentiate between energy-types in this analysis. As such, a different value is determined for the likelihood of coal-fired and natural gas-fired generation, since technology and investment paths are quite different between feedstocks.

Although many factors can play a role in increasing the likelihood of efficiency improvement, five indicators reflective of a range of both demand and supply dynamics are included. These indicators assess different risk areas that can encourage efficiency as a means to improve resource supply security. To calculate the final index, each indicator is given a different weighted value, so as to represent its relative influence on generation infrastructure efficiency improvements. The specific weights are determined through a correlation analysis, which measures the relationship strength between the given indicator and each economy's projected efficiency investment. Over time, the weight of each indicator will vary since changes in an economy's economic development level can sway the influence of any given variable.

The indicators included and their respective weights are as follows: plant age structure (existing generation capacity) [44 percent], per capita consumption of imported energy for power generation [18 percent], power generation demand growth (cumulative 2005-2030) [16 percent], power generation energy import dependency [12 percent], and thermal average efficiency level [10 percent].

This index relies on 2005 data and future projections to calculate the improvement potential through to 2030. The data used for this index was collected from APERC's *APEC Energy Demand and Supply Outlook 2006 – Economy Review*, International Energy Agency (IEA) statistics, and other official government sources.

A brief discussion of each indicator is described below:

Plant age structure (existing generation capacity) is currently the most influential driver that impacts efficiency improvement. This indicator determines how much generation capacity will require either retrofitting or replacement from 2005 to 2030. Currently, more than 50 percent of the capacity in the region is reaching retirement age. Plants that are near retirement age, older than 35 years, generally have a lower overall conversion efficiency and operate below design conditions. As such, these plants use more energy per unit of desired output, which increases an economy's total primary energy demand requirement. As resources become more constrained, the likelihood to replace these old plants increases. By replacing aging plants, an economy can steadily increase its average efficiency level and enhance its resource security.

An economy's per capita consumption of imported energy for power generation is a proxy for the potential degree of supply risk, which in turn points to the likelihood for efficiency improvement. As economies use more energy, they have greater incentive to reduce the sector's energy intensity, since it reduces the need for the acquisition of additional resources. As such, they are less vulnerable to market changes including price hikes and resource shortages. As part of a future energy security plan, policymakers are more likely to reduce the sector's intensity if it is deemed as a point of vulnerability.

The portion of an economy's consumption that comes from imports is used in this analysis because a significant share of APEC economies are net energy importers and the degree of supply risk is highly dependant on supply acquisition. In consideration of the region's limited resource supply and fickle international energy markets, certain economies that lack sufficient purchasing power may prefer to focus on domestic improvements to meet demand. As the prices of energy inputs increase, this variable will play greater importance.

Power generation demand growth (2005 to 2030) is a proxy that measures the requisite increase of current generation output through the retrofit of existing plants or new capacity additions.

To model the scale and pace of investment, each economy's demand growth is indexed to the average growth for developed economies in the region (which has a slope close to zero). The greater the demand growth, the more likely an economy is to focus on retrofitting current plants and adding new capacity to augment current generation output. As economies reach economic maturity, their demand growth stabilises. Thus, they are less likely to require investment in additional capacity, which decreases the possibility to improve efficiency.

Power generation energy import dependency, similar to the previous two indices, is an efficiency improvement feedback mechanism related to resource acquisition. It measures the specific risk associated with acquiring foreign energy supply to meet electricity demand. This indicator takes into account the impact that a given energy's imports have on the entire power generation sector.

APERC's Outlook shows that APEC will become a net importer of natural gas by 2015 and coal by 2030. As local energy trade diminishes, economies will resort to importing resources from farther distances, which will increase the final import cost of energy inputs. In the midst of higher fuel costs, economies are more likely to gravitate towards an investment in energy efficiency to reduce import requirements.

Thermal average efficiency level, although ranked lower, is a critical factor affecting the necessity for improvement. This indicator is a proxy for the cost-benefit margin involved with implementing an efficiency improvement.

As an economy's average efficiency level gets closer to (1) the market's highest cycle efficiencies and/or (2) the theoretical efficiency limit for each type of power generation, it is less likely to invest in further improvements. At these higher efficiency levels, the incremental benefit of an improvement is less than the cost to implement this change. In order to achieve the highest levels of efficiency, economies would have to introduce the most efficient technologies in the market and these are still considerably cost prohibitive. Conversely, economies that are more inefficient have greater incentive to improve their efficiency level since the potential long-term benefits outweigh the cost of implementation.