Costs of Fossil Fuel Generating Plant

Report to the Ministry of Economic Development

By East Harbour Management Services Ltd

May 2002

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Introduction

The following brief report has been prepared in response to a request by the New Zealand Ministry of Economic Development. The report sets out costs and performance for a range of fossil fuelled electricity generating technologies likely to be used over the next 25 years. Likely station sizes are presented along with an adjustment mechanism for alternative sizes. The material will form part of the Ministry of Economic Development energy database and an input into the next "Energy Outlook" to be published.

Technologies

Technologies have been chosen that are expected to be the bulk of fossil fuelled electricity generating plant over the next 25 years. These technologies are:

- Conventional Pulverised Coal with Flue Gas Desulphurisation (FGD)
- Fluidised Bed Coal Combustion
- Integrated Coal Gasification Combined Cycle (ICGCC)
- Gas Combined Cycle
- Advanced Gas Combined Cycle
- Combustion Turbine
- Advanced Combustion Turbine
- Generic Distributed Generation

The size of plant included in this study is limited to that likely to be used for wholesale generation of electricity except for the generic Distributed Generation plant which has been included for comparison.

A brief description of each of these technologies is given in Appendix A.

Current Costs and Performance

Capital costs, plant efficiencies and operating and maintenance costs for the chosen technologies are given in Table 1.

Initial cost data was sourced from the "Annual Energy Outlook 2001" prepared by the American Energy Information Administration (EIA). This data was adjusted for New Zealand conditions where possible. The adjustment procedure is outlined in Appendix B, with all costs adjusted to New Zealand dollars as at September 2001. The costs are indicative only and individual plant costs will vary according to the site, special conditions and constraints. Typical plant sizes have been chosen.

Points to note:

- Capital costs, efficiencies and operating and maintenance (O&M) costs for fluidised bed plant are assessed to be the same as those for conventional pulverised coal steam plant with flue gas desulphurisation (FGD). For this reason, it has not been separately listed in the following tables.

- The output and efficiencies quoted for gas-fired plant apply for a natural gas fuel. Natural gas firing gives a slightly higher output than distillate firing by about 2% for a given gas turbine. The efficiency is also slightly higher by about 4% when burning gas, i.e. multiply the efficiency given in the text for gas firing by 0.96 to obtain the efficiency when firing distillate.

- Distributed generation has been included. Even though the unit size is small there could be sufficient numbers of units to make a significant contribution.

- The specific capital costs generally apply to plant that is close to the size of plant quoted. Scaling factors for different sized plant are given in Appendix C.

Table 1: Current Power Station Capital, Operating and Maintenance Costs, and Efficiency

Technology	Size	Capital Cost [4]	O & M Cost [4]		Efficiency
			Fixed	Variable	
	MW	$/kW	$/kW	c/kWh	%
Conventional Pulverised Coal with FGD [1,2]	400	2330	45	0.80	36
Integrated Coal Gasification Combined Cycle	400	2840	62	0.19	43
Gas Combined Cycle	400	856	30	0.12	45
Advanced Gas Combined Cycle	400	1229	28	0.12	49
Combustion Turbine	160	706	12	0.02	30
Advanced Combustion Turbine	120	986	17	0.02	37
Generic Distributed Generation (Base Loaded) [3]	2	1297	8	3.56	31
Note 1: Fluidised bed plant has similar capital and O&M costs to pulverised coal plant with FGD					
Note 2: For a pulverised coal plant without FGD deduct $416/kW from the capital cost					
Note 3: Fuel costs need to be below $8.7/GJ to keep electricity costs below 15c/kWh					
Note 4: Costs are in September 2001 New Zealand dollars					

Technological Learning and Adoption

Invention, innovation and diffusion are the three phases successful new technologies pass through. Diffusion is the gradual process of adoption of a process or product by potential users. This induces "learning by doing" for manufacturers and "learning by using" by consumers. "Learning by doing" on an international basis results in cost reductions due to manufacturing efficiencies and experience. This is reflected in the "learning factors" applied to each technology. Diffusion of new economically superior technologies typically follow an S shaped curve, slow at the start, becoming faster, and slower as saturation is approached.

Future Costs and Efficiencies

Costs given in the tables 2 to 8 have learning factors built into them. These take into account the reductions in cost that occur as plants move from the demonstration stage to initial commercialisation (where a few units are built) to full commercialisation (where many plants are built). Technological improvements that are expected to occur such as increased efficiency are also included.

"Low" and "high" technology uptake scenarios have been included to indicate the spread of values with the "expected value" the most likely case.

In the "low" technology uptake scenario, the costs and efficiencies of advanced generating technologies (i.e. Advanced Gas Combined Cycle and Advanced Combustion Turbine) remain at current levels. Learning is applied to the "expected" technology cases. In the "high" technology uptake scenario, efficiencies of advanced fossil generating technologies are based on the United States Department of Energy, Office of

Fossil Energy's Vision 21 programme goals. This scenario represents the upper limits of efficiencies considered to be achievable within the next 15 years.

Vision 21, builds on a portfolio of technologies already being developed, including low-polluting combustion, gasification, high efficiency furnaces and heat exchangers, advanced gas turbines, fuel cells, and fuels synthesis, and adds other critical technologies and system integration techniques.

Capital costs and efficiencies for each of the technologies will be dealt with in turn.

Table 2: Conventional Pulverised Coal/ Fluidised Bed Steam Cycle

	Capital Cost $/kW			Efficiency %		
	Technology Uptake			Technology Uptake		
Year	Low	Expected	High	Low	Expected	High
2001	2330	2330	2330	36.2	36.2	36.2
2012	2260	2260	2260	37.5	37.5	37.5
2025	2186	2186	2186	37.5	37.5	37.5

Chart 1a

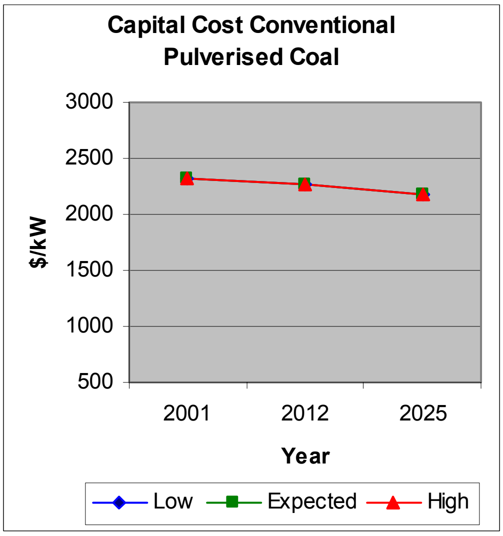

Chart 1b

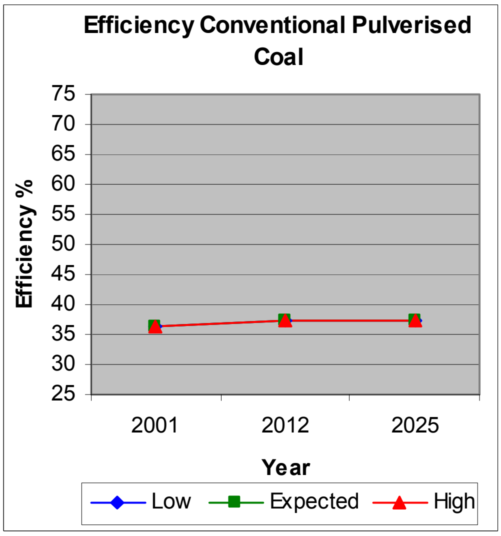

Table 3: Integrated Coal Gasification Combined Cycle

	Capital Cost $/kW			Efficiency %		
	Technology Uptake			Technology Uptake		
Year	Low	Expected	High	Low	Expected	High
2001	2840	2840	2840	42.8	42.8	42.8
2012	2840	2619	2124	42.8	49.0	56.1
2025	2840	2510	2008	42.8	49.0	60.0

Chart 2a

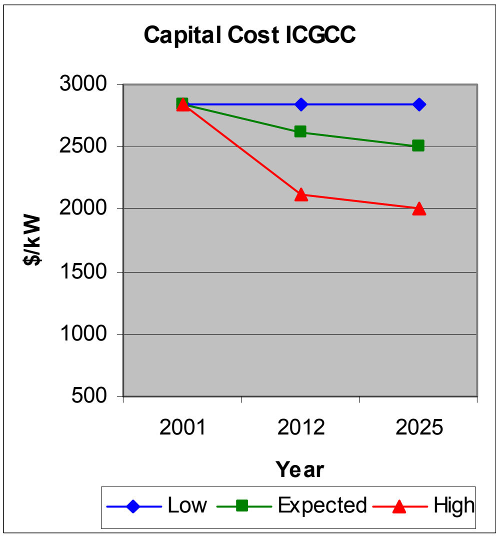

Chart 2b

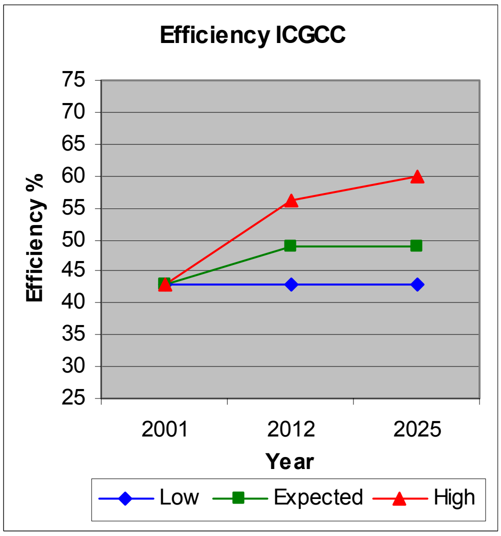

Table 4: Gas Combined Cycle

	Capital Cost $/kW			Efficiency %		
	Technology Uptake			Technology Uptake		
Year	Low	Expected	High	Low	Expected	High
2001	856	856	856	45.4	45.4	45.4
2012	832	832	832	49.9	49.9	49.9
2025	804	804	804	49.9	49.9	49.9

Chart 3a

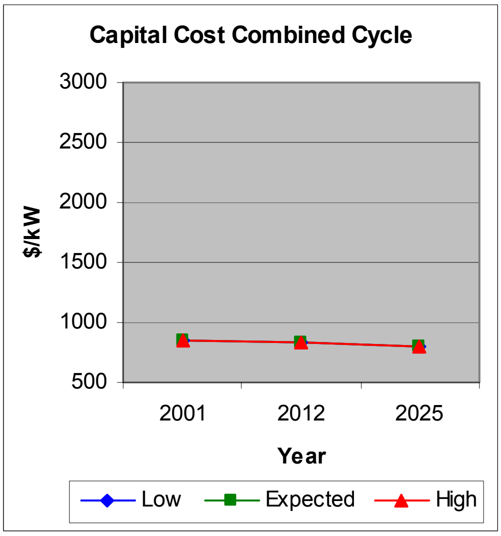

Chart 3b

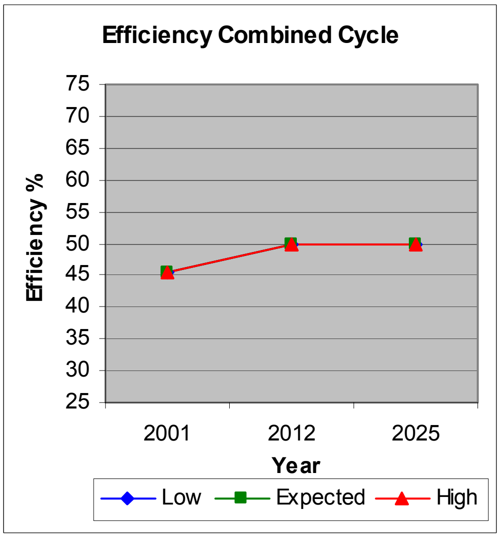

Table 5: Advanced Gas Combined Cycle

	Capital Cost $/kW			Efficiency %		
	Technology Uptake			Technology Uptake		
Year	Low	Expected	High	Low	Expected	High
2001	1229	1229	1229	49.3	49.3	49.3
2012	1229	1056	1045	49.3	53.7	65.0
2025	1229	970	952	49.3	53.7	70.0*

* In the latest AEO 2002 published in December 2001 this efficiency has been revised down to 68.8%.

Chart 4a

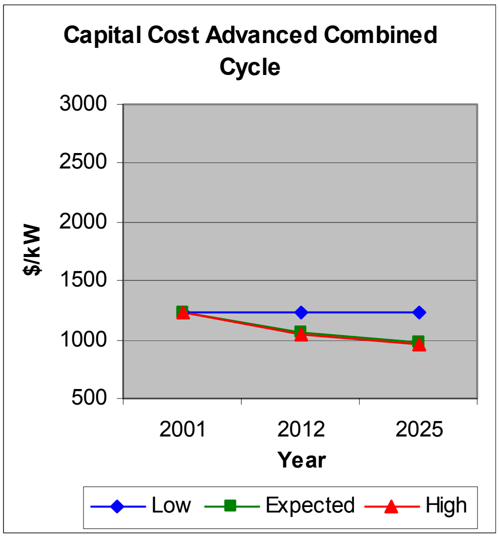

Chart 4b

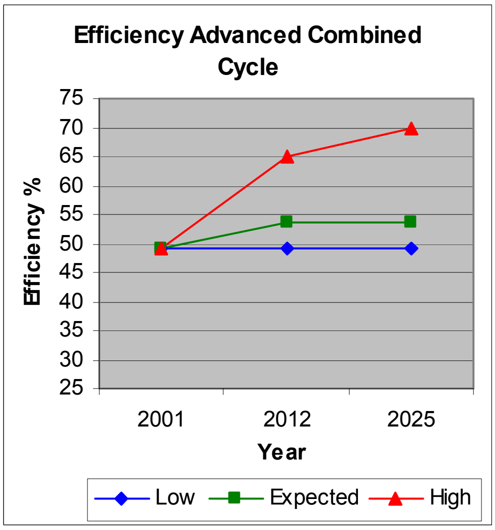

Table 6: Combustion Turbine

	Capital Cost $/kW			Efficiency %		
	Technology Uptake			Technology Uptake		
Year	Low	Expected	High	Low	Expected	High
2001	706	706	706	29.8	29.8	29.8
2012	706	684	684	29.8	32.2	32.2
2025	706	661	661	29.8	32.2	32.2

Chart 5a

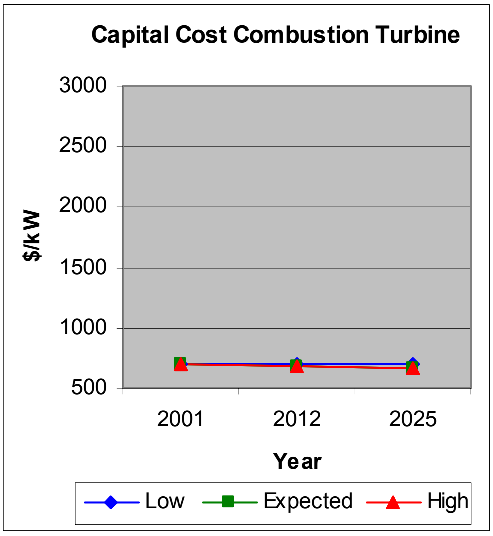

Chart 5b

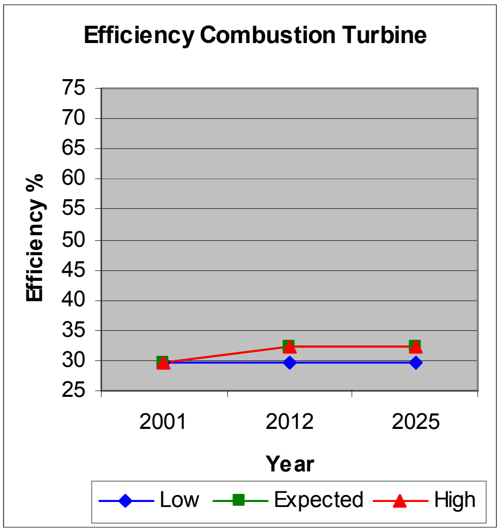

Table 7: Advanced Combustion Turbine

	Capital Cost $/kW			Efficiency %		
	Technology Uptake			Technology Uptake		
Year	Low	Expected	High	Low	Expected	High
2001	986	986	986	37.4	37.4	37.4
2012	986	795	791	37.4	42.6	50.2
2025	986	750	735	37.4	42.6	50.2

Chart 6a

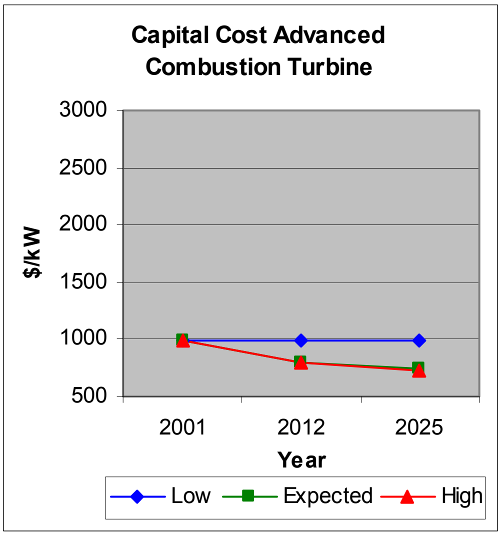

Chart 6b

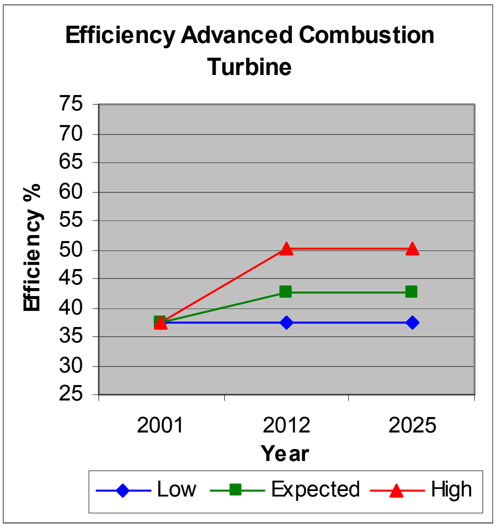

Table 8: Generic Distributed Generation (Base Loaded)

	Capital Cost $/kW			Efficiency %		
	Technology Uptake			Technology Uptake		
Year	Low	Expected	High	Low	Expected	High
2001		1297			31	
2012		1195			37	
2025						

Technologies represented in this generic Distributed Generation technology include micro turbines, combustion turbines, compression ignition engines and fuel cells.

Distributed Generation (DG) and Combined Heat and Power (CHP) applies to relatively small generating units at or near consumer sites. In CHP costs are shared between heat and electricity. DG technologies cover a range of renewable and thermal plant options.

Load Factor

Load factors have not been specified for each type of plant. The New Zealand electricity market is a deregulated one operating on supply and demand. Actual load factor for generating plant will depend on the price bid into the market and if the plant is dispatched. New plant tends to have higher efficiency than existing plant and therefore will tend to generate ahead of older plant and so will operate around the 90% level. It may however be less reliable in the first one to two years as teething problems are sorted out. As more efficient plant or renewables are brought on-line then the load factor may drop. For example, in recent years New Plymouth power station’s (33% efficiency) load factor has been at around 25% while Huntly power station’s (36% efficiency) has been 40%. A more detailed discussion is given in Appendix D.

Electricity Generation Costs

Indicative current electricity costs (2001) are shown in Table 9. Conventional pulverised coal plant without FGD has been included for comparison as this would be an option if low sulphur coal was available. In these examples a discount factor of 10% has been used over a 20-year plant life. Gas and coal prices of $3/GJ and $2.5/GJ respectively have been used. The net load factor has been assumed to be 90%.

Table 9: Electricity Costs in 2001 (10% discount factor, 20 year life, $3/GJ gas, $2.5/GJ coal, 90% load factor)

Technology	Cost c/kWh				
	Capital	**Fuel**	**O & M**	**Other**	**Total**
Conventional Pulverised Coal with FGD	4.3	2.5	1.5	1.4	9.7
(Conventional Pulverised Coal without FGD)	3.5	2.5	1.2	1.1	8.3
Integrated Coal Gasification Combined Cycle	5.2	1.8	1.1	1.6	9.7
Gas Combined Cycle	1.4	2.4	0.5	0.4	4.7
Advanced Gas Combined Cycle	2.1	2.2	0.6	0.6	5.5
Combustion Turbine	1.1	3.6	0.2	0.3	5.2
Advanced Combustion Turbine	1.5	2.9	0.3	0.4	5.1

The effects of the capital costs and efficiency changing through time are shown in Appendix D. The costs are sensitive to changes to capital, fuel and O&M costs, plant factors and discount rates. The effects of some of these on the various unit cost components are also shown in Appendix D. Unit costs range from 4.0 to 7.6 c/kWh for gas based technologies and from 6.7 to 10.1 c/kWh for coal based technologies.

In cases where the costs of generation from a type of technology are similar other factors such as environmental considerations may be included. In these cases combined cycle plant are likely to be preferred because of their more efficient use of the gas and lower environmental effects.

Conclusions

- Generation costs for base loaded gas-based wholesale electricity generation technologies tend to fall in the 4 c/kWh to 6 c/kWh area, whereas coal is in the 6 to 10 c/kWh area.

- At fixed input assumptions, and higher load factors, all gas-fired technologies are at a similar unit cost; while all coal fired technologies are at similar (but greater) unit cost.

- The unit cost of coal-fired plant is heavily influenced by both capital and fuel costs, while unit costs for gas fired plant are dominated by fuel cost.

- It is anticipated that capital, operation, maintenance costs and efficiencies will change through time. There is expected to be a larger decrease in unit costs for advanced technologies up to 2012 with little change after that as they mature.

- Reducing the discount rate from 10% to 5% reduces the capital cost component for coal-fired plant by about 1.7 c/kWh and 0.5 c/kWh for gas fired plant. Increasing the fuel cost by $0.5/GJ increases the fuel component of the electricity cost for both fuels by about 0.4 c/kWh.

- Unless there is a dramatic fall in coal technology capital and operating costs or a dramatic rise in gas prices to around $9/GJ little of this coal plant may be installed over the review period.

- On the other hand niche markets such as Distributed Generation could experience high gas prices due to their small size, opening opportunities for small coal plant.

- Similarly niche opportunities for coal may exist in the South Island where the only gas alternative is LPG but where thermal plant must compete with abundant hydro resources.

- The advanced gas turbine appears to be the most economical over the widest plant factor range just losing out to the gas turbine in a peaking role when the load factor is below 30%. For base loaded plant the advanced gas turbine with its low capital cost and good efficiency has slight economic advantages over the more complex combined cycles with their higher capital costs and higher efficiencies. Nevertheless, current focus remains on gas combined cycle plant.

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Website of the Office of Fossil Energy, U.S. Department of Energy, Washington, DC http://www.energy.gov/

Appendix A: Technology Descriptions

Conventional Pulverised Coal with FGD

In a conventional plant pulverised coal is burnt in a boiler to produce steam, which is fed into a steam turbine coupled to an electrical generator. Emission controls such as electrostatic precipitators or bag houses, and flue gas desulphurisation (FGD) limit pollutants to permitted levels. A typical example of this type of plant is Huntly power station except that it does not have FGD because of low sulphur levels in NZ coals.

Expected changes with time will be increased steam temperatures and pressures leading to higher efficiencies coupled with more effective environmental controls.

Fluidised Bed Coal Combustion

Fluidised beds suspend solid fuels on upward-blowing jets of air during the combustion process. The result is a turbulent mixing of gas and solids, much like a bubbling fluid. The mixing action of the fluidised bed brings the flue gases into contact with a sulphur-absorbing chemical, such as limestone or dolomite. More than 95 percent of the sulphur pollutants in coal can be captured inside the boiler by the sorbent.

Fluidised bed boilers can burn almost any combustible material, from coal to municipal waste, and are capable of meeting sulphur dioxide and nitrogen oxide emission standards without the need for expensive add-on controls.

Integrated Coal Gasification Combined Cycle (ICGCC)

Rather than burning coal directly, coal gasification reacts coal with steam and controlled amounts of air or oxygen under high temperatures and pressures to produce a gaseous mixture, typically hydrogen and carbon monoxide. These hot, coal gases exiting the gasifier are used to power a gas turbine (in the same manner as natural gas). Hot exhaust from the gas turbine is then fed to a heat recovery steam generator (HRSG). The steam from the HRSG is then fed to a conventional steam turbine, producing a second source of power (just as in a combined cycle plant).

Pollutant-forming impurities and greenhouse gases can be separated from the gaseous stream. Unreacted solids can be collected and marketed.

Gasification is used today in refineries and chemical plants, but the technology is still in the demonstration phase for electric power generation.

Combustion Turbine (Gas Turbine)

Combustion of the fuel produces a high-temperature, high-pressure gas working fluid. When this is exhausted through a gas turbine this causes the shaft to rotate by expanding the gas through a series of specially designed blades. The rotating shaft drives an electric generator and a compressor for the inlet air used by the gas turbine. Many turbines also use a heat exchanger called a recuperator to add turbine exhaust heat into the combustor's air/fuel mixture.

Gas turbines are compact, lightweight, easy to operate, and come in sizes ranging from several hundred kilowatts to hundreds of megawatts.

Examples of this type of plant are the old gas turbines at Whirinaki and Otahuhu power stations. Current gas turbines are more efficient.

Advanced Combustion Turbine

This type of combustion turbine can operate at higher temperatures through the use of more exotic materials and other enhancements to achieve higher efficiencies.

Gas Combined Cycle

Fuel, generally natural gas but can be other gaseous or liquid fuels, is burned in a gas turbine coupled to an electrical generator. Exhaust heat from the gas turbine is then passed into a heat recovery steam generator (HRSG), which can be fired or unfired. The steam is then fed to a conventional steam turbine to provide a second source of power. Otahuhu B Power Station and the most recent Stratford Power Station are examples of this type of plant but at the time of ordering they would have been considered to be more in the advanced class of combined cycle plant.

Advanced Gas Combined Cycle

This is a type of combined cycle plant utilising higher temperatures through the use of more exotic materials and other enhancements to achieve higher efficiencies.

Distributed Generation

Distributed Generation (DG) strategically applies relatively small generating units (typically less than 30 MWe) at or near consumer sites to meet customer needs, to support economic operation of the existing power distribution grid, or both. DG technologies cover a range of renewable and thermal plant options.

Thermal technologies such as gas turbines and reciprocating engines are already making a contribution. Microturbines and fuel cells are beginning to enter the market, but will require additional research and development to realize widespread adoption. Also, fuel cell/turbine hybrid systems and 21st century fuel cells, currently in the embryonic stage, offer even greater potential.

Appendix B: Cost Adjustment Procedure

Capital Cost Adjustment

Base costs in 1999 US $ were first adjusted for US inflation using U.S. Bureau of Labor Statistics, PPI index “Turbines and turbine generator sets”. 80% of this amount was converted to $NZ using a conversion rate of $NZ = US$ 0.42. The remaining 20% was considered New Zealand content.

Operations and Maintenance Adjustment

The procedure was the same as for the capital cost adjustment except that 67% of the US$ was converted to $NZ.

Appendix C Adjustment of Capital Costs for Unit Size

The specific capital costs generally apply to plant that is close to the size of plant that has been quoted. Scaling factors are used to estimate the specific cost of plant of a different size. Capital costs tend to obey power laws in terms of relation to size.

An estimate of a different size of plant can be found by applying the following formula

$$C = C_{known} \times (S_{known} / S)^n$$

Where C is the unknown cost
C_{known} is the known cost
S_{known} is the known size
S is the size for which the cost is to be calculated
n is the scaling factor

The following table C1 gives approximate capital cost scaling factors over a limited range, say ± 50%.

Table C1: Capital Cost Scaling Factors

Technology	Scaling Factor "n"
Simple cycle gas turbine	0.4
Combined cycle gas turbine (CCGT)	0.22
Integrated gasification combined cycle (IGCC)	0.28
Pulverised coal fuel	0.28
Fluidised bed plant	0.28

Appendix D: Changes Through Time and Unit Cost Sensitivities

Electricity Demand and Generation

The total load on a power system is seldom constant; rather, it varies widely with hourly, daily, weekly, monthly, or annual changes in the requirements of the area served. It is strongly influenced by seasonal factors. Extremes of temperature contribute to higher demand as heating and air conditioning units consume more power. The difference between day and night demand is even more marked. The minimum system load for a given period is termed the base load. In New Zealand it tends to be supplied from hydro, geothermal and combined cycle plant. Maximum loads, resulting usually from temporary conditions, are called peak loads, and the operation of the generating plants must be closely coordinated with fluctuations in the load. The peaks, usually being of only a few hours' duration are frequently served by gas combustion-turbine or hydro generating units.

The New Zealand electricity market is a deregulated one operating on supply and demand. Periods of peak demand enable generators to command higher prices. Where shortfalls in supply are foreseen, then a generator may choose to install new generation, either as base load plant to displace other plant into a peaking role, or as a specific peaking plant. The price a generator sets for its peaking plant dispatch is whatever the market will bear, but can be reasonably set to ensure that all necessary capital and operating costs are recovered over its short operating period. As all generators receive the same price as the last plant dispatched to meet demand, windfall gains would be possible for all generators. For this reason, to avoid unnecessary benefit to competitors, it is unlikely that dedicated peaking plant will be built for the current market. Demand however is seldom at peak, meaning that plant may at times sit idle, not generating revenue. The general objective is to obtain a mix of "Base Load" plant which covers normal demand, and "Peak Load" plant, which can be relied on at short notice as needed.

Thermal peaking plant is characterised by a lower capital cost than base load plant but expensive to run, allowing cost recovery over a shorter operating period. The plant is designed for rapid start up. With an integrated hydro-based system in New Zealand, the need for specifically designated peaking plant has been minimal. Hydro stations or existing thermal stations can perform this function. Peaking stations such as Otahuhu A, Stratford and Whirinaki have had minimal operation. Load factors can be less than 3%.

Load Factors

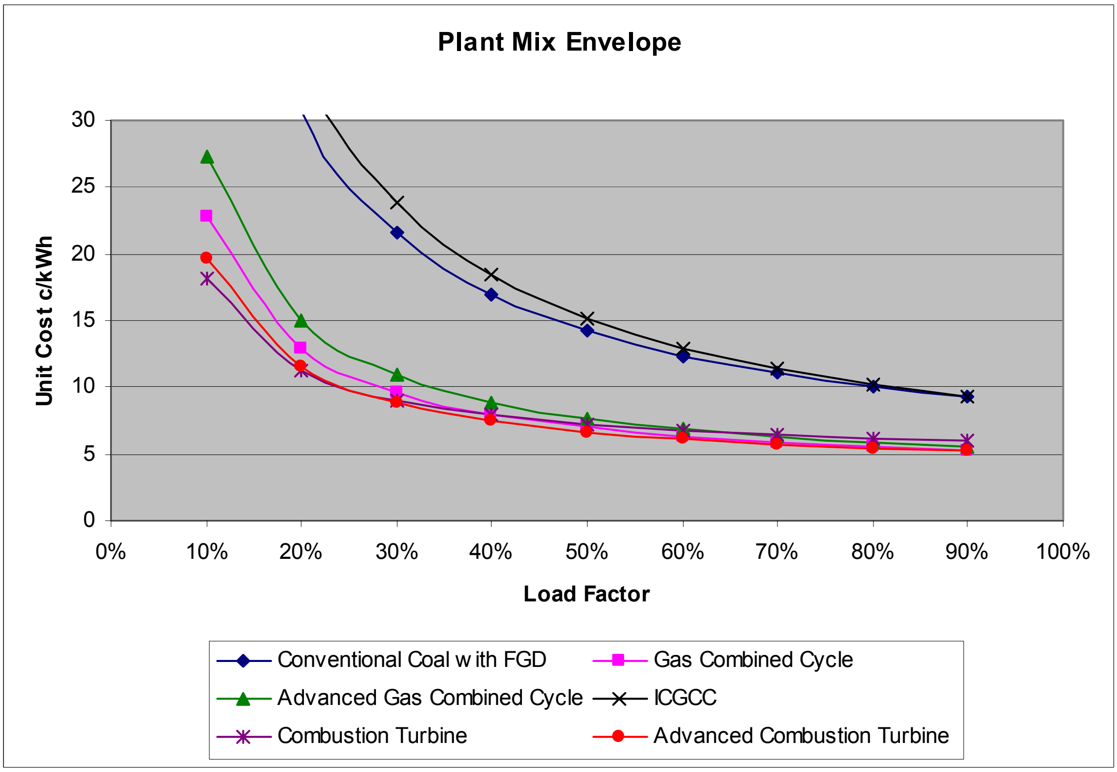
Load factors have not been specified for each type of plant. All the plant can achieve high load factors exceeding 90%. Actual load factor will depend on merit order of operation and the nature of fuel contracts. New plant tends to have higher efficiency than existing plant and therefore will tend to generate ahead of older plant and so will operate at the 90% level. They may however be less reliable in the first one to two years as teething problems are sorted out. As more efficient plant or renewables are brought on-line then the load factor may drop. For example, in recent years New Plymouth power station's (33% efficiency) load factor has been at around 25% while Huntly power station's (36% efficiency) load factor has been 40%.

Special contracts may override these efficiency considerations. For instance, the Taranaki Combined Cycle plant has a long-term "take or pay" fuel contract and a "contract for difference" (cfd) arrangement for most of its generation that fixes major expenditure and guarantees necessary income. The cfd allows the plant to be offered at zero price to the market enabling base load operation for the life of the cfd.

To illustrate the effect of load factor on generation cost, the cost of generation in 2012 of the various technologies over a range of plant factors is shown in Chart D1. Gas has been priced at $4/GJ and coal at $2.5/GJ, the plant life is 20 years and a discount rate of 10% has been used.

In this simplified case the advanced gas turbine, gas combined cycle and the advanced gas combined cycle have the lowest annual costs over a wide range of load factors. High capital and O&M costs make coal clearly uncompetitive with these gas-based technologies. Because of the uncertainties associated with each technology it is difficult to predict which type would be best for a particular application. Which plant is best for a peaking or base load would depend upon the specific conditions at the time. In the example the advanced gas turbine appears to be the most economical over the widest plant factor range just losing out to the gas turbine in a peaking role when the load factor is below 30%. In the advanced gas turbine case the low capital cost and good efficiency has economic advantages over the more complex combined cycles with their higher capital costs and higher efficiencies.

Chart D1: Effect of Load Factor on Annual Cost (2012, 10% discount factor, 20 year life $4/GJ gas, $2.5/GJ coal)



Changes Through Time and Discount Factor and Fuel Price Effects

Capital cost repayments and fuel costs tend to be the two largest components of the cost of electricity. To illustrate the effect of changing these components, several scenarios have been constructed. These have discount factors of 5% and 10%, gas prices of $3/GJ, $4/GJ and $5/GJ and coal prices of $2/GJ and $2.5/GJ. The net load factor has been assumed to be 90% and the life of the plant is 20 years. Tables D1 to D18 show these costs for 2001, 2012 and 2025.

Table D1: 2001 Electricity Costs with a 5% Discount Rate, Gas $3/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	**Fuel**	**O & M**	**Other**	**Total**
	5% Discount Rate	Gas $3/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	2.6	2.0	1.5	0.6	6.7
Integrated Coal Gasification Combined Cycle	3.2	1.7	1.1	0.8	6.8
Gas Combined Cycle	0.9	2.4	0.5	0.2	4.0
Advanced Gas Combined Cycle	1.3	2.2	0.6	0.3	4.4
Combustion Turbine	0.7	3.6	0.2	0.1	4.6
Advanced Combustion Turbine	1.0	2.9	0.3	0.2	4.4

Table D2: 2001 Electricity Costs with a 5% Discount Rate, Gas $4/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	**c/kWh**				
	Capital	**Fuel**	**O & M**	**Other**	**Total**
	5% Discount Rate	Gas $4/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	2.6	2.0	1.5	0.6	6.7
Integrated Coal Gasification Combined Cycle	3.2	1.7	1.1	0.8	6.8
Gas Combined Cycle	0.9	3.2	0.5	0.2	4.8
Advanced Gas Combined Cycle	1.3	2.9	0.6	0.3	5.1
Combustion Turbine	0.7	4.8	0.2	0.1	5.8
Advanced Combustion Turbine	1.0	3.9	0.3	0.2	5.4

Table D3: 2001 Electricity Costs with a 5% Discount Rate, Gas $5/GJ, Coal $2.5/GJ, 90% Load Factor, 20 year life

Technology	**c/kWh**				
	Capital	**Fuel**	**O & M**	**Other**	**Total**
	5% Discount Rate	Gas $5/GJ, Coal $2.5/GJ			
Conventional Pulverized Coal with FGD	2.6	2.5	1.5	0.6	7.2
Integrated Coal Gasification Combined Cycle	3.2	2.1	1.1	0.8	7.2
Gas Combined Cycle	0.9	4.0	0.5	0.2	5.6
Advanced Gas Combined Cycle	1.3	3.7	0.6	0.3	5.9
Combustion Turbine	0.7	6.0	0.2	0.1	7.0
Advanced Combustion Turbine	1.0	4.8	0.3	0.2	6.3

Table D4: 2001 Electricity Costs with a 10% Discount Rate, Gas $3/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	10% Discount Rate	Gas $3/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	4.3	2.0	1.5	1.3	9.1
Integrated Coal Gasification Combined Cycle	5.2	1.7	1.1	1.7	9.7
Gas Combined Cycle	1.4	2.4	0.5	0.4	4.7
Advanced Gas Combined Cycle	2.1	2.2	0.6	0.6	5.5
Combustion Turbine	1.1	3.6	0.2	0.3	5.2
Advanced Combustion Turbine	1.5	2.9	0.3	0.4	5.1

Table D5: 2001 Electricity Costs with a 10% Discount Rate, Gas $4/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	10% Discount Rate	Gas $4/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	4.3	2.0	1.5	1.3	9.1
Integrated Coal Gasification Combined Cycle	5.2	1.7	1.1	1.7	9.7
Gas Combined Cycle	1.4	3.2	0.5	0.4	5.5
Advanced Gas Combined Cycle	2.1	2.9	0.6	0.6	6.2
Combustion Turbine	1.1	4.8	0.2	0.3	6.4
Advanced Combustion Turbine	1.5	3.9	0.3	0.4	6.1

Table D6: 2001 Electricity Costs with a 10% Discount Rate, Gas $5/GJ, Coal $2.5/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	10% Discount Rate	Gas $5/GJ, Coal $2.5/GJ			
Conventional Pulverized Coal with FGD	4.3	2.5	1.5	1.3	9.6
Integrated Coal Gasification Combined Cycle	5.2	2.1	1.1	1.7	10.1
Gas Combined Cycle	1.4	4.0	0.5	0.4	6.3
Advanced Gas Combined Cycle	2.1	3.7	0.6	0.6	7.0
Combustion Turbine	1.1	6.0	0.2	0.3	7.6
Advanced Combustion Turbine	1.5	4.8	0.3	0.4	7.0

Table D7: 2012 Electricity Costs with a 5% Discount Rate, Gas $3/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	5% Discount Rate	Gas $3/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	2.6	1.9	1.5	0.6	6.6
Integrated Coal Gasification Combined Cycle	3.0	1.5	1.1	0.7	6.3
Gas Combined Cycle	0.9	2.2	0.5	0.2	3.8
Advanced Gas Combined Cycle	1.1	2.0	0.6	0.2	3.9
Combustion Turbine	0.7	3.4	0.2	0.1	4.4
Advanced Combustion Turbine	0.8	2.5	0.3	0.2	3.8

Table D8: 2012 Electricity Costs with a 5% Discount Rate, Gas $4/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	5% Discount Rate	Gas $4/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	2.6	1.9	1.5	0.6	6.6
Integrated Coal Gasification Combined Cycle	3.0	1.5	1.1	0.7	6.3
Gas Combined Cycle	0.9	2.9	0.5	0.2	4.5
Advanced Gas Combined Cycle	1.1	2.7	0.6	0.2	4.6
Combustion Turbine	0.7	4.5	0.2	0.1	5.5
Advanced Combustion Turbine	0.8	3.4	0.3	0.2	4.7

Table D9: 2012 Electricity Costs with a 5% Discount Rate, Gas $5/GJ, Coal $2.5/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	5% Discount Rate	Gas $5/GJ, Coal $2.5/GJ			
Conventional Pulverized Coal with FGD	2.6	2.4	1.5	0.6	7.1
Integrated Coal Gasification Combined Cycle	3.0	1.8	1.1	0.7	6.6
Gas Combined Cycle	0.9	3.6	0.5	0.2	5.2
Advanced Gas Combined Cycle	1.1	3.4	0.6	0.2	5.3
Combustion Turbine	0.7	5.6	0.2	0.1	6.6
Advanced Combustion Turbine	0.8	4.2	0.3	0.2	5.5

Table D10: 2012 Electricity Costs with a 10% Discount Rate, Gas $3/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	10% Discount Rate	Gas $3/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	4.1	1.9	1.5	1.3	8.8
Integrated Coal Gasification Combined Cycle	4.8	1.5	1.1	1.5	8.9
Gas Combined Cycle	1.4	2.2	0.5	0.4	4.5
Advanced Gas Combined Cycle	1.8	2.0	0.6	0.5	4.9
Combustion Turbine	1.1	3.4	0.2	0.3	5.0
Advanced Combustion Turbine	1.2	2.5	0.3	0.3	4.3

Table D11: 2012 Electricity Costs with a 10% Discount Rate, Gas $4/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	10% Discount Rate	Gas $4/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	4.1	1.9	1.5	1.3	8.8
Integrated Coal Gasification Combined Cycle	4.8	1.5	1.1	1.5	8.9
Gas Combined Cycle	1.4	2.9	0.5	0.4	5.2
Advanced Gas Combined Cycle	1.8	2.7	0.6	0.5	5.6
Combustion Turbine	1.1	4.5	0.2	0.3	6.1
Advanced Combustion Turbine	1.2	3.4	0.3	0.3	5.2

Table D12: 2012 Electricity Costs with a 10% Discount Rate, Gas $5/GJ, Coal $2.5/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	10% Discount Rate	Gas $5/GJ, Coal $2.5/GJ			
Conventional Pulverized Coal with FGD	4.1	2.4	1.5	1.3	9.3
Integrated Coal Gasification Combined Cycle	4.8	1.8	1.1	1.5	9.2
Gas Combined Cycle	1.4	3.6	0.5	0.4	5.9
Advanced Gas Combined Cycle	1.8	3.4	0.6	0.5	6.3
Combustion Turbine	1.1	5.6	0.2	0.3	7.2
Advanced Combustion Turbine	1.2	4.2	0.3	0.3	6.0

Table D13: 2025 Electricity Costs with a 5% Discount Rate, Gas $3/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	5% Discount Rate	Gas $3/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	2.5	1.9	1.5	0.6	6.5
Integrated Coal Gasification Combined Cycle	2.9	1.5	1.1	0.7	6.2
Gas Combined Cycle	0.9	2.2	0.5	0.2	3.8
Advanced Gas Combined Cycle	1.1	2.0	0.6	0.2	3.9
Combustion Turbine	0.7	3.4	0.2	0.1	4.4
Advanced Combustion Turbine	0.8	2.5	0.3	0.2	3.8

Table D14: 2025 Electricity Costs with a 5% Discount Rate, Gas $4/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	5% Discount Rate	Gas $4/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	2.5	1.9	1.5	0.6	6.5
Integrated Coal Gasification Combined Cycle	2.9	1.5	1.1	0.7	6.2
Gas Combined Cycle	0.9	2.9	0.5	0.2	4.5
Advanced Gas Combined Cycle	1.1	2.7	0.6	0.2	4.6
Combustion Turbine	0.7	4.5	0.2	0.1	5.5
Advanced Combustion Turbine	0.8	3.4	0.3	0.2	4.7

Table D15: 2025 Electricity Costs with a 5% Discount Rate, Gas $5/GJ, Coal $2.5/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	5% Discount Rate	Gas $5/GJ, Coal $2.5/GJ			
Conventional Pulverized Coal with FGD	2.5	2.4	1.5	0.6	7.0
Integrated Coal Gasification Combined Cycle	2.9	1.8	1.1	0.7	6.5
Gas Combined Cycle	0.9	3.6	0.5	0.2	5.2
Advanced Gas Combined Cycle	1.1	3.4	0.6	0.2	5.3
Combustion Turbine	0.7	5.6	0.2	0.1	6.6
Advanced Combustion Turbine	0.8	4.2	0.3	0.2	5.5

Table D16: 2025 Electricity Costs with a 10% Discount Rate, Gas $3/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	10% Discount Rate	Gas $3/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	4.0	1.9	1.5	1.3	8.7
Integrated Coal Gasification Combined Cycle	4.6	1.5	1.1	1.5	8.7
Gas Combined Cycle	1.3	2.2	0.5	0.4	4.4
Advanced Gas Combined Cycle	1.6	2.0	0.6	0.5	4.7
Combustion Turbine	1.0	3.4	0.2	0.3	4.9
Advanced Combustion Turbine	1.2	2.5	0.3	0.3	4.3

Table D17: 2025 Electricity Costs with a 10% Discount Rate, Gas $4/GJ, Coal $2/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	10% Discount Rate	Gas $4/GJ, Coal $2/GJ			
Conventional Pulverized Coal with FGD	4.0	1.9	1.5	1.3	8.7
Integrated Coal Gasification Combined Cycle	4.6	1.5	1.1	1.5	8.7
Gas Combined Cycle	1.3	2.9	0.5	0.4	5.1
Advanced Gas Combined Cycle	1.6	2.7	0.6	0.5	5.4
Combustion Turbine	1.0	4.5	0.2	0.3	6.0
Advanced Combustion Turbine	1.2	3.4	0.3	0.3	5.2

Table D18: 2025 Electricity Costs with a 10% Discount Rate, Gas $5/GJ, Coal $2.5/GJ, 90% Load Factor, 20 year life

Technology	c/kWh				
	Capital	Fuel	O & M	Other	Total
	10% Discount Rate	Gas $5/GJ, Coal $2.5/GJ			
Conventional Pulverized Coal with FGD	4.0	2.4	1.5	1.3	9.2
Integrated Coal Gasification Combined Cycle	4.6	1.8	1.1	1.5	9.0
Gas Combined Cycle	1.3	3.6	0.5	0.4	5.8
Advanced Gas Combined Cycle	1.6	3.4	0.6	0.5	6.1
Combustion Turbine	1.0	5.6	0.2	0.3	7.1
Advanced Combustion Turbine	1.2	4.2	0.3	0.3	6.0