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LCA OF THE QUEENSLAND ELECTRICITY GRID
(Year Ending 2004)

TECHNOLOGY ASSESSMENT REPORT 61

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EXECUTIVE SUMMARY

This report gives the results of a life cycle analysis (LCA) for the supply of 1 MWh of electricity to the Queensland grid for YEJ 2004, with a generation capacity of ~10,650MW. This report is part of a series of LCA studies of the Australian State grids, which are being undertaken for comparison with the benchmark data sets generated for the same systems in 2001. The analysis takes into account all power supplied from power stations on the Queensland interconnected grid, but excludes interstate transfers. The analysis includes systems associated with power generation, transmission and distribution.

The study aims to provide a more detailed, transparent and disaggregated evaluation of Queensland's electricity grid than reported in other studies (which have focused on greenhouse gas emissions alone). The study includes a range of indicators including resource energy and fresh water consumption as inputs, and greenhouse gas emissions (GGEs), NO_x, SO_x, particulates and solid waste emissions, as well as a range of substances sourced from the National Pollutant Inventory (NPI) database, as outputs. Being LCA-based, it also includes emissions from the supply of other materials and services for mining, transportation, generation and distribution.

The results are summarised in the following table, which includes inputs and outputs for this study, as well as the benchmarks provided by the previous study in 2001. Figures are on an annual basis for the Queensland grid. Comparisons with overall Queensland values (from all major combustion, agricultural, waste and fugitive activities) are also included, to provide context.

Parameter	QLD grid 2000-01 (per annum)	QLD - all sources (per annum)	% of State	QLD grid 2003-04 (per annum)	QLD - all sources (per annum)	% of State
Resource energy	435.1 PJ	1,041 PJ	41.8	511.1 PJ	1,164 PJ	43.9
Fresh water	66.2 GL	3,242GL	2.0	85.9 GL	4,711 GL	1.8
GGE	39.2 Mt CO_2-e	112 Mt	35.0	46.1 Mt CO_2-e	145.11 Mt	31.8
NO_x	159 kt	290 kt	54.8	168 kt	320 kt	52.5
SO_x	113 kt	470 kt	24.0	141 kt	430 kt	32.8
Particulates	29.3 kt	152.73 kt	19.2	35.4 kt	160 kt	22.1

The table below shows the average consumption and emissions related to power generation on a MWh from transmission and distribution grid basis.

Parameter	2001 Transmission grid	2001 Distribution grid	2004 Transmission grid	2004 Distribution grid	Difference [a] (%)
Inputs					
Resource energy (GJ)	11.41	12.08	10.91	11.58	- 4.4%
Fresh water (m^3)	1.74	1.84	1.83	1.95	+ 4.6%
Outputs					
GGE (kg CO_2-e)	1028	1088	983	1044	- 4.4%
NO_X (kg)	4.14	4.41	3.61	3.83	- 12.8%
SO_X (kg)	2.96	3.13	3.01	3.20	+ 1.7%
Particulates (kg)	0.77	0.81	0.76	0.80	- 1.3%
Solid waste (kg)	87.8	92.9	84.9	90.1	- 3.3%

[a] Based on transmission grid

Key findings are:

- On a state-wide basis, activities associated with electricity supply account for a significant proportion of state resource consumption totals, with the exception of fresh water which is insignificant in comparison with total water consumed in Queensland (includes agriculture). There has been a small increase in the grid's share of energy resource consumption. This is due to the accelerating increase in demand for electricity in Queensland, compared to other energy consumers.
- The system overall has improved in efficiency since 2001 as shown by the decrease in resource energy consumption per MWh output (11.41 to 10.91, representing an efficiency improvement from 31.55% to 33.00%). This is due to the retirement of Callide A and Swanbank A, in conjunction with the addition of Millmerran, Tarong North and Swanbank E CCGT, which exhibit higher efficiencies.
- Water consumption increased over the past three years on a MWh basis. This was due to Stanwell reporting a much higher water consumption level in this period. As Stanwell is a major generator, this has a significant effect on the total water consumption of the grid.
- The grid accounts for significant amounts of emissions, particularly GGE, NO_x, SO_x and particulate matter.
  - The grid has improved its greenhouse intensity on a per MWh basis reducing from 1028 kg/MWh in 2001 to 983 kg/MWh in 2004. Greenhouse emission intensity decreased in line with the decrease in required energy resource per unit of output. It is expected that if the government is successful with its program to increase gas generated electricity in the state, greenhouse gas intensity will decrease further.

- NO_x emissions from power generation have a greater than 50% share in NO_x emissions for the entire state. However, this percentage has decreased since 2001 from 54.8% to 52.8% of the state total. There has been a considerable decrease in NO_x emissions per MWh of output over this time. The 12.8% reduction in NOx emission intensity has been the result of the replacement of old power stations with new, lower NO_x emitting stations. Additionally, Callide power plant has managed to decrease it's NO_x intensity by 62% over this period according to the NPI. The main contributors towards NOx emissions are Tarong, Gladstone, Stanwell and Callide B.
- SO_x emissions from power generation are the second highest in the state behind the Mount Isa Copper Smelter, with a total share of 32.8%. The grid had a considerably larger share of the state total this year than it did in 2001 although the SO_x intensity of the grid increased by only 1.7%. Gladstone's SO_x emissions increased from 1.9 kg/MWh in 2001 to 3.5 kg/MWh in 2004 according to NPI data, and as a major contributor to the grid, this had a large impact on the increase in SO_x intensity of the whole system.
- The majority of the particulate emissions for the Queensland grid are due to coal mining operations. Tarong became the largest source of PM_{10} emissions in this period, with a significant increase (50%) in reported PM_{10} emissions relative to 2001. This was offset by reductions from other parts of the life cycle, giving a net decrease in emissions on a per MWh basis.

- Current details on transmission and distribution losses were unavailable. The present study used the 1997 transmission loss value published by the ESAA of 5.3%. The current value for distribution loss was obtained from the ESAA 2003 (1 year previous to this study) and was 5.82%, (compared to 5.5% in 2001).

There were a few areas identified for further investigation, which will allow improvements in the quality and the relevance of the analysis:

- Improved data is required (disaggregated) for the Queensland natural gas system (wellhead CO_2 stripping, leakage). The present analysis has used estimates based on average Australian data (including lower GGE NW shelf gas), which is believed to have considerably lower GGE than the present Queensland gas system. This discrepancy will be of increased significance if proposed natural gas based plants are constructed. However, this data was assumed not to change between 2001 and 2004.
- Details on transmission and distribution losses are required from ESAA to improve the accuracy of data and to allow for improved comparison between Australian states.

INTRODUCTION

The purpose of this Life Cycle Analysis is to determine the environmental impacts of power generation in Queensland, based on a range of key performance indicators. The basis of the study is the generation of 1 MWh of electricity supplied from transmission and distribution grids. Contributions from interstate generators are not included.

The study aims to provide collated information on the entire integrated power generation grid, including coal mines, transportation and provision of other consumables.

Data is sourced from a range of publicly available sources (some of which are conflicting) and the most representative data has been used – based on prior studies.

1.1 National grids

The installed capacity for grid, and larger non-grid, generators is summarised in Table 1 below (includes co-generation and renewables). The Queensland grids generation capacity was the second largest in Australia at June 2003, with a total installed capacity of 10,646 MW.

Table 1 Power generation capacity of Australian States (June 2003)[1]

State	Principal plant (MW)	Non-grid generators (MW)	Cogeneration (MW)	Total (MW)	% of total
NSW & ACT	12,231	501	265	12,997	25.7
Qld	10,646	615	164	11,425	22.5
VIC	8,441	489	352	9,282	18.3
SA	3,459	192	274	3,925	7.7
WA	3,273	1,691	911	5,875	11.6
NT	504	230	106	840	1.7
Tas	2,542	29	16	2,58787	5.1
SMHEA	3,756	-	-	3,756	7.4
Total	44,852	3,751	2,087	50,690	100

1.2 Queensland grid[1,2,3]

In FY2004, a total of 49,484 GWh of electricity was sent out by Queensland power stations to the transmission grid. Table 2 gives details of the principal stations and the other grid connected (embedded) facilities on the Queensland grid – including operating company, type, capacity, and generated power, forming the basis for the LCA.

Table 2 Queensland electricity grid data (excludes purchases from interstate)

Station	Operating company	Type	Capacity (MW)	Year commissioned	Fuel	GWh sent out (2003-04)	GWh sent out (% QLD)
Tarong	Tarong Energy	Pf boiler	1400	1984-86	Coal	10,764	21.8
Tarong North	Tarong Energy	Pf boiler	450	2003	Coal	3,485	7.0
Gladstone	Comalco/NRG	Pf boiler	1680	1976-82	Coal	7,483	15.1
Stanwell	Stanwell Corporation	Pf boiler	1400	1993-96	Coal	8,382	16.9
Millmerran	Intergen	Pf boiler	840	2003	Coal	4,526	9.1
Callide A	CS Energy	Pf boiler	120	1998	Coal	0	
Callide B	CS Energy	Pf boiler	700	1988/89	Coal	4,910	9.9
Swanbank A[3]	CS Energy	Pf boiler	408	1966-69	Coal	0	
Swanbank B	CS Energy	Pf boiler	500	1970-73	Coal	2,192	4.4
Collinsville	Transfield Services	Pf boiler	190	1998	Coal	539	1.1
Callide Power Plant	CS Energy/ Intergen	Pf boiler	800	2001	Coal	5,621	11.4
Kareeya	Stanwell Corporation	Hydro	72	1957/59	Hydro	405	0.8
Barron Gorge	Stanwell Corporation	Hydro	60	1963	Hydro	160	0.3
Barcaldine	Enertrade	CCGT	53	1993	NG	104	0.2
Roma	Origin Energy	OCGT	76	1999	NG	21	0.0
Mt Stuart	Origin Energy	OCGT	288	1999	Oil	24	0.0
Mackay	Stanwell Corporation	OCGT	34	1976	Oil	0.4	0.0
Oakey	Oakey Power Holdings	OCGT	320	2000	Gas or diesel	39	0.1
Swanbank C	CS Energy	OCGT	26	1973	NG	0	
Swanbank D	CS Energy	OCGT	37	1999	NG	4.7	0.0
Swanbank E[1]	CS Energy	CCGT	385	2002	NG	616	1.2
Yabulu[4]	Transfield Holdings	OCGT	165	1999	NG	2.2	0.0
Wivenhoe	Tarong Energy	Pumped hydro[2]	500	1984	Hydro	206	0.4
Total			10,094			49,484	99.7

1. Coal seam methane
2. Pumped storage hydro scheme is a net consumer of power
3. Decommissioned in July 2002
4. Conversion to 220MW combined cycle plant due to be finished in 2006

Losses from high and low voltage transmission and distribution grids are also taken into account in this LCA, with the distribution grid having the greatest influence. Powerlink operates the high voltage transmission grid, and Transenergié is responsible for the Queensland/New South Wales Interconnector (QNI). The low voltage distribution grid is controlled by Energex (Metropolitan), Ergon Energy (Regional) and Country Energy, a New South Wales distributor whose supply area extends across the Queensland border. Losses will be discussed further in section 2.2.2

1.3 Primary Queensland generators

The primary generators contributing to the Queensland electricity system are Enertrade, CS Energy, Stanwell Corporation, Tarong Energy Corporation, Origin Energy and Intergen. There is also a grid interconnection with New South Wales.

1.3.1 Enertrade[4]

Enertrade is the trading name of the Queensland Power Trading Corporation, a wholesale energy trader owned by the Queensland Government. Enertrade owns the gas fired power station at Barcaldine and also purchases all electricity from the privately owned Gladstone, Collinsville, Yabulu and Oakey power stations through Power Purchase Agreements, and trades this into the National Electricity Market.

Barcaldine power station (1993)

Barcaldine is a combined cycle power station located 750 km west of Rockhampton. It is the only power station that Enertrade owns and operates. The station is fuelled by natural gas from South West Queensland and is one of the most thermally efficient power stations in Australia. The exhaust gases from the gas turbine produce steam that powers a supplementary steam turbine, producing a total capacity of 53 MW. The gas turbine was completed in 1993, and the steam turbine was added in 1999. Barcaldine achieves an annual average thermal efficiency of ~45% (HHV).

Gladstone power station (1976/82)

Gladstone is a subcritical pf fired power station located just to the west of Gladstone. It is the largest coal fired station in Queensland. Gladstone has a capacity of 1680 MW (6x280 MW generating units). Coal is delivered by rail from Central Queensland. The station was completed in 1982 and is operated by NRG Gladstone Operating Services. Gladstone achieves an annual average sent out thermal efficiency of ~35% (HHV)

Collinsville power station (1998)

Collinsville is a subcritical pf fired power station located to the northwest of Mackay and fuelled on locally mined coal. Collinsville has a capacity of 190 MW (4x31 MW and 1x66 MW generating units). The units were originally completed in 1976, but were completely refurbished in 1999 after the plant was sold to Transfield and NRG. The station is now owned and operated by NRG as an intermediate plant, shutting down over weekends in winter. The station achieves an annual average sent out thermal efficiency of ~26% (HHV).

Yabulu power station (1999)

Yabulu is a kerosene fuelled gas turbine located to the north of Townsville that currently operates as a peaking plant to provide support to the grid during extreme weather and plant outages. Yabulu’s current capacity is 165 MW. There is currently development underway at the site to convert the station to combined cycle, and increase its capacity to 220 MW. The station will operate as a base load provider, and as such, will be the first base load plant in the north Queensland region. The upgrade is being conducted by Transfield who is also the owner and operator of the plant. The refurbished plant is planned to be completed in 2006. Yabulu currently has an annual sent out efficiency of ~31% (HHV).

Oakey power station (2000)

Oakey is a fuel oil/gas fired gas turbine power station located 150 km to the west of Brisbane and was completed in 2000. Oakey has a capacity of 320 MW and operates as a peaking plant. Much of the gas used at this station is sourced from coal seam methane. The plant is owned and operated by Oakey Power Holdings Pty Ltd. Oakey has an annual sent out thermal efficiency of 30% (HHV).

1.3.2 CS Energy[5,6]

CS energy owns and operates Callide and Swanbank power stations, has a 50% share in the Callide power plant, and also owns a remote station at Mica creek. They are also responsible for the development of the new coal fired station (Kogan creek) which is due to be completed in September 2007.

Callide power station (1998, 1988/89)

Callide power station is located in central Queensland, near Biloela, and consists of two subcritical pf fired installations (Callide A & B). Coal is supplied from the nearby Callide mine. Evaporative cooling towers are used to cool water from the condensers in both plants. Callide A has a capacity of 120 MW (4x30 MW generating units), and was originally built in 1965. It was then refurbished and recommissioned in April 1998. It was placed on standby reserve in December 2001 and remains on standby pending the development of a new aluminium smelter in Gladstone. Callide A has an annual sent out thermal efficiency of ~24% (HHV).

Callide B, commissioned in 1988/89, has a capacity of 700 MW (2x350 MW generating units). Callide B has an annual sent out thermal efficiency of ~35% (HHV).

Swanbank power station (1966-69, 1970-73, 1999, 2002)

Swanbank power station, near Ipswich in southeast Queensland, consists of two coal-fired installations (Swanbank A & B) and three gas turbines (Swanbank C, D & E). Coal is sourced from local coal mines.

Swanbank A is a subcritical pf fired power station constructed in the 1960s, and has a capacity of 408 MW (6x68 MW generating units). The station was decommissioned in July 2002.

Swanbank B is subcritical pf fired, was constructed in the 1970s, and has a capacity of 500 MW (4x125 MW generating units). Swanbank B has an annual sent out thermal efficiency of ~32% (HHV). As a result of its recent refurbishment, Swanbank B will continue to provide vital intermediate and peaking power to the Queensland market to 2011.

Swanbank C gas turbine (commissioned in 1973) was decommissioned in the 2003 calendar year; this decreased the capacity of the Swanbank complex by 26 MW. Swanbank D remains as a standby unit and can produce 37 MW of electricity. It runs on diesel and was commissioned in 1999. Swanbank D has an annual sent-out thermal efficiency of ~ 29%.

Swanbank E is a 385 MW combined cycle gas turbine which sources its fuel (coal seam methane) from the Scotia gas field via the Roma to Brisbane pipeline. The unit, commissioned in November 2002, is one of the newest, and is Australia's most efficient power generating unit, with less than half the greenhouse gas emissions of coal-fired plants. Swanbank E has an annual sent out thermal efficiency of ~50%.

Callide Power Plant (2001)

Callide Power Plant, (Callide C), is a supercritical pf fired power station located close to the original Callide power station near Biloela in Queensland. Callide Power Plant has a capacity of 800 MW (2x400 MW generating units). The first 400 MW unit of this $800 million joint venture between InterGen and CS Energy was completed in July 2001, with the second 400 MW generator officially opened in November 2001. Callide Power Plant achieves an annual average sent out thermal efficiency of ~39% (HHV) – one of the best in Australia.

1.3.3 Stanwell Corporation[7]

Stanwell Corporation owns and operates Stanwell power station, a major contributor to the Queensland grid, as well as Mackay Gas Turbine and Kareeya Hydro which are smaller grid connected stations.

Stanwell power station (1993/96)

Stanwell is a subcritical pf fired power station located 22 km west of Rockhampton. Stanwell has a capacity of 1,400 MW (4×350 MW generating units) and operates as a base load station. Coal for the power station is sourced mostly from Curragh and Blackwater coal mines. First producing electricity in 1993, the fully automated, coal-fired power station became fully operational in 1996, at a total cost of $1.6 billion. Condenser cooling is via large natural draft evaporative cooling towers. Stanwell achieves an annual sent out thermal efficiency of over 35% (HHV).

Mackay power station (1976)

Mackay is an oil fired open cycle gas turbine located at Mackay, 800 km north of Brisbane. Mackay has a capacity of 34 MW and operates as a peaking station (remote controlled). It has an annual sent out thermal efficiency of ~28% (HHV).

1.3.4 Tarong Energy Corporation[8]

Tarong Energy, a Queensland Government Owned Corporation (GOC), is an active competitor in the National Electricity Market (NEM) generating about one quarter of Queensland's electricity supply. Established in 1997, they own and operate two coal fired plants in Queensland, Tarong and Tarong North, as well as Wivenhoe hydro plant.

Tarong power station (1984/86, 1983)

Tarong is a subcritical pf fired power station located at Nanango, 180 km northwest of Brisbane, and is one of Queensland's largest power stations. With a total generating capacity of 1,400 MW (4x350 MW generating units), Tarong generates base load power for the Queensland grid. The first of Tarong's four generating units became operational in May 1984 and the station was completed in 1986. In all, the project employed more than 2000 people and cost more than $1.2 billion. Coal is supplied via conveyor from Meandu coal mine.

Cooling water for the natural draft evaporative cooling towers is via pipeline from Boondooma dam. Tarong achieves an annual sent out thermal efficiency of 35%-36% (HHV).

Tarong North Power Station (2003)

Tarong North is a 450 MW supercritical pf fired power station located on the same site as Tarong power station. The Tarong North Power Station is owned by a 50/50 Joint Venture between Tarong Energy and TM Energy (Aust) Pty Ltd, and is operated by Tarong Energy under contract with the joint venture. Tarong North has an annual sent-out efficiency of over 37%.

Wivenhoe power station (1984)

Wivenhoe power station is a pumped storage hydroelectric plant, located on the eastern side of Wivenhoe Dam, about 90 kilometres northwest of Brisbane. Wivenhoe has a capacity of 500 MW (2x250 MW generating units), and is used for peaking loads. As a pumped storage facility, it is important to recognise that this facility is a net consumer of electricity.

1.3.5 Origin Energy[9]

Origin energy is one of Australia's leading gas and electricity providers. Origin owns and operates Mt Stuart and Roma power stations in Queensland, as well as one non-grid connected station, Bulwer Island.

Roma power station (1999)

Roma is a natural gas fired open cycle gas turbine located in the Surat Basin region of Queensland, 300 km west of Brisbane. Roma has a capacity of 76 MW (2x38 MW generating units) and operates as a peaking station. It has an assumed annual sent out thermal efficiency of ~30% (HHV).

Mt Stuart power station (1999)

Mt Stuart is a kerosene fuelled gas turbine power station located to the south of Townsville. Mt Stuart has a capacity of 288 MW (2x144 MW generating units) and operates as a peaking plant. The plant was commissioned in 1999 and is owned and operated by Origin Energy, after it was purchased from AES Corporation in late 2002. It is planned to convert the plant from kerosene to natural gas and expand to combined cycle, thereby increasing the capacity by up to 150 MW. Mt Stuart currently has an annual sent out efficiency of ~33% (HHV).

1.3.6 Intergen

Intergen owns one the latest addition to the Queensland electricity grid, Millmerran power station. They also have a 50% share in Callide power plant.

Millmerran power station (2003)

Millmerran power station is located in South West Queensland. It sources its coal from the nearby Commodore coal mine, and problems with water consumption are alleviated through the use of dry cooling. It is a supercritical pf plant, and as such, operates at a high efficiency. Commissioned in 2003, it has a capacity of 800 MW and is designed to emit 10% less greenhouse gases than conventional coal fired generators. Millmerran power station has an annual sent-out efficiency of ~40%.

1.4 Future generating capacity[1]

In 2002/03, (latest available data), the capacity factor of the Queensland grid was 53.1% (ie the installed capacity was operating at an average of 53.1% of full load over the entire year). Over the same period, the capacity factors for NSW and Victoria were 56.5% and 65.8%, respectively.

The peak load for the Queensland grid in 2002/03 was 7,105 MW on the 31st January 2003.

Although the capacity factor for the grid is relatively low, several new plants are being planned/under development to supply anticipated growth in power requirements. The proposed Queensland plants are listed in Table 3.

Table 3 Proposed power stations in Queensland

Plant	Developer	Type	Size (MW)	Fuel Type	Proposed commission year
Kogan Creek	AQC & CEPA	Steam	750	Coal	2007
Peak Downs	BHP	Steam	230	Coal	N/a
Surat Coal Field	Surat Dawson Development	Steam	470	Coal	N/a
Townsville	Stanwell	CCGT	766	NG	N/a
Wambo (Kogan)	ERM Power /AIDC	GT	450	NG	2007
West Surat	MIM/Entergy	Steam	700	Coal	N/a
Yabulu (conversion to CBM)	Enertrade	CCGT	60	CBM	N/a

2 LCA METHODOLOGY

This study is based on a cradle-to-gate analysis for the generation, transmission and distribution of power in Queensland. The study excludes the construction of power stations and also excludes non-grid generation (mostly small and remote facilities), and grid-connected facilities which do not result in net export of power (eg Bulwer Island). Losses due to pumped storage are included in transmission losses.

2.1 Functional unit

The functional unit is 1 MWh of electricity supplied from the Queensland grid (transmission and distribution) in the 12 months ending June 2004.

2.2 System boundary

The system boundary encompasses resource extraction, transportation, provision of other fuels and consumables and emissions associated with the generation of 1 MWh of electricity from the Queensland grid (see Figure 1).

Interstate purchases of electricity are not included in the study.

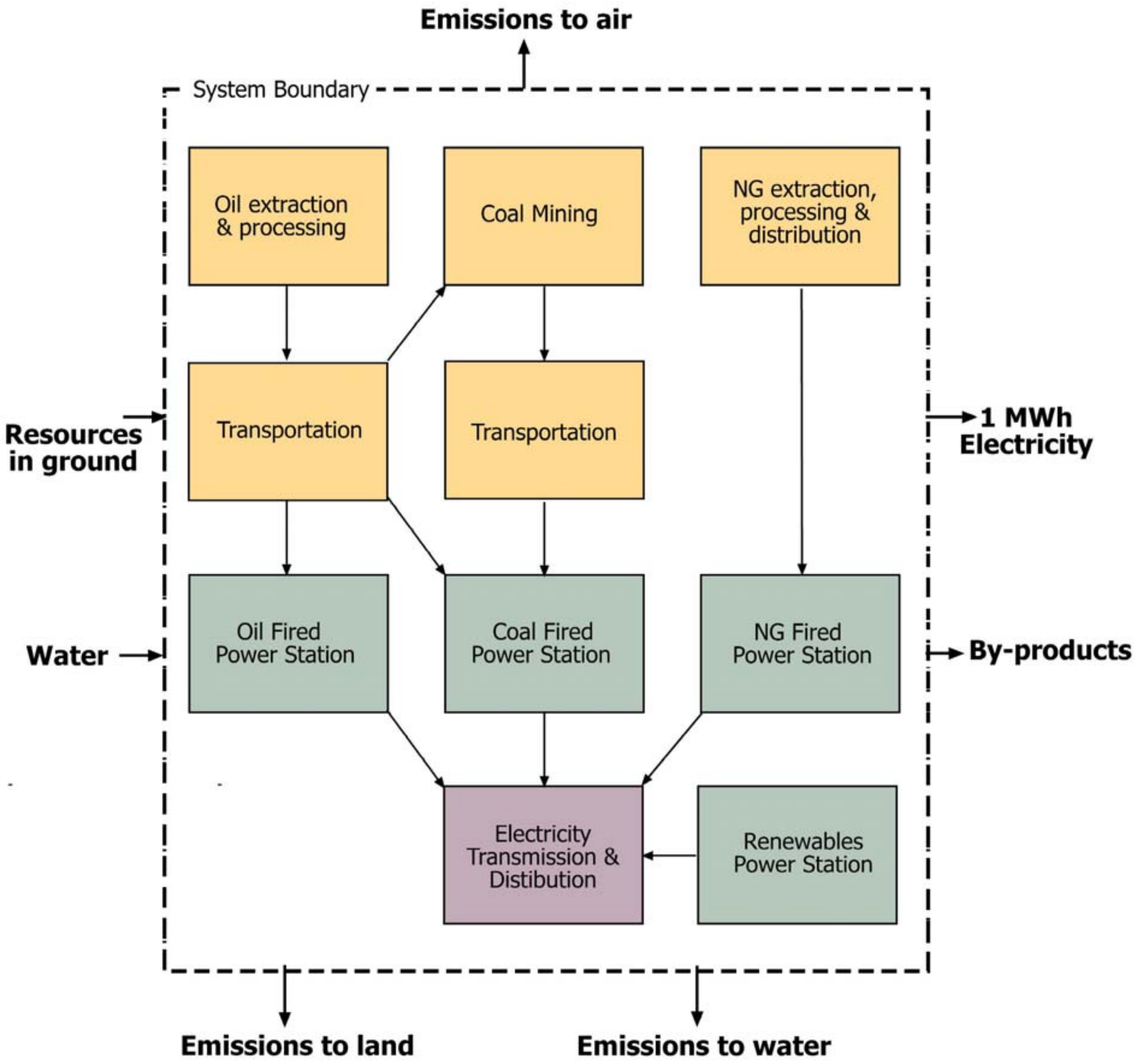

Figure 1 LCA system boundary

2.2.1 Power plant data

Data for the primary plants are summarised in Table 4, using information sourced from the Electricity Supply Association of Australia[1,2,3] and other publicly available reports including the National Greenhouse Gas Inventory Workbook for Fuel Combustion (Stationary Sources)[10], company annual and environment reports[11,12,13], the National Pollutant Inventory (NPI)[14], and others[15].

Table 4 Efficiency and emissions data for the primary generators contributing to the Queensland transmission grid – on a station basis. (NPI values shaded)

Station	Efficiency[a] (%)	CO_2[b] (kg/MWh)	NO_x (kg/MWh)	SO_x (kg/MWh)	PM_{10} (kg/MWh)	Fresh water (m^3/MWh)
Tarong	35.0	906	4.48	2.48	0.90	2.62
Tarong North	37.4	851	1.7	1.88	0.05	2.15
Barcaldine	45.0	398	0.35	Not reported	0.03	Not reported
Millmerran	40.0	748	1.52	3.37	0.24	0.225
Gladstone	35.0	934	5.12	3.43	0.12	0.02
Stanwell	35.3	909	3.24	3.59	0.13	2.15
Mount Stuart	32.7	802	1.02	0.05	0.08	Not reported
Callide B	35.1	967	3.95	1.65	0.27	2.35
Swanbank B	32.1	934	2.89	4.69	0.08	3.0
Swanbank E	50.0	358	0.07	~ 0	0.02	Not reported
Collinsville	26.3	1220	4.15	8.41	0.2	1.64
Callide Power Plant	39.1	869	1.14	1.6	0.08	1.50

a) HHV, sent out basis
b) Calculated from fuel composition, allowing for 99% of carbon in fuel converted to CO_2

Construction

The construction of power stations and infrastructure was not included in this case study, as previous LCAs have shown that power station construction contributes only a small amount to the overall resource consumption and emissions. This generalisation is not applicable for renewable technologies.

Emissions

For fossil fuelled power generation technologies, it is assumed that 99% of the carbon in coal and 99.5% of carbon in natural gas and oil is converted to CO_2 in the combustion process (as is used in the Australian NGGIC Workbook for Fuel Combustion [10]).

Other power station emissions, and emissions for power generation externalities (eg coal mining, chemical production etc) are included, and are sourced from the Australian National Greenhouse Gas Inventory Workbooks[10,16,17], US EPA and the Australian National Pollutant Inventory[14].

Cooling

The cooling systems at each of the major coal fired power stations depend on the location of the plant. The coastal power station (Gladstone), utilises saltwater cooling with large volumes of sea water, whereas the inland stations usually use recirculated cooling water systems with cooling provided by evaporative cooling towers, with makeup from rivers, dams or lakes. Millmerran, located in south west Queensland utilises dry cooling, and so has minimal fresh water consumption compared to other plants.

Waste management

The majority of waste produced in the supply of grid power is coal ash from coal-fired stations (includes both fly ash and bottom ash). Most fly ash is collected in bag houses or electrostatic precipitators, mixed with bottom ash and pumped or conveyed to tailings dams.

At selected power stations, some of the ash is classified and transported to cement, or cement batching plants, where it is used as a cement extender. This accounted for approximately 10% of the total coal ash in Queensland in 2004. However, the exact breakdown of current ash utilisation is unclear. Fly ash can be added for several purposes (including, for example, concrete pumpability) which changes the effective replacement rate for Portland cement from 1:1 (cement: fly ash replacement) for small additions, to 1:1.5 for larger additions. There are also numerous other low value applications (low in both economic and environmental benefits), such as for land stabilisation. The percentage of generated ash that is recycled is shown in Table 5 for the companies that report this information.

Table 5- Ash recycling at selected plants

Operator	Power station	Percentage of Coal ash recycled (%)
Tarong Energy	Tarong	22
	Tarong North	0
CS Energy	Callide B	10
	Callide C	12.5
	Swanbank B	40
Stanwell Corporation	Stanwell	1,000 tonnes (~ 0.22%)[a]

a) estimate based on 99% ash content of consumed coal

It should be noted that most coal-fired stations use either run-of-mine coal, or a middlings fraction from washeries (for the production of export coals). Therefore, for the purposes of the present study, coal washery reject waste streams have not been allocated to the power from the Queensland grid.

2.2.2 Transmission and distribution

Losses of electricity in transmission were sourced from the Electricity Supply Association of Australia 1997 report[18], and distribution losses were sourced from the Electricity Supply Association of Australia 2004 report[1]. These values represent a weighted average loss from the entire grid. In Queensland these losses were 5.3% for high voltage transmission and 5.82% for distribution.

Table 6 Comparison of transmission and distribution losses for different grids (2003)

Grid	Transmission losses (%)	Distribution losses (%)
NSW	2.7	5.63
Queensland	5.3	5.82
Victoria	2.5	5.97
WA[1]	-	7.84

1. WA distribution losses include transmission losses

2.2.3 Coal

Coal is the primary fuel used for power generation in Queensland. Approximately 22.4 Mt was used in 2004, all from domestic supply. Table 7 gives the approximate quantity of coal used at each of the major power stations, and the mode and distance of transport for each source.

Table 7 Coals used in major Queensland power stations

Station	Coals used	Amount (Mt)	Mode of transport	Distance (km)
Millmerran	Commodore	2.24	Conveyor	2
Callide B	Callide (Southern)	2.52	Conveyor	5
Callide C	Callide (Southern)	2.58	Conveyor	5
Collinsville	Collinsville	0.28	Conveyor	10
Gladstone	Callide (Boundary Hill) Curragh	3.3 0.29	Rail Rail	315 315
Swanbank B	Ebeneezer Jeebropilly Wilkie Creek	0.32 0.54 0.13	Road Road Rail	22 55 220
Stanwell*	Curragh Blackwater	1.26 1.90	Rail Rail	200 200
Tarong*	Meandu	5.07	Conveyor	1
	Jeebropilly	0.36		
Tarong North*	Meandu	1.63	Conveyor	1
	TOTAL	22.42		

* Numbers are from annual reports.

The weighted average coal composition for each station is given in Table 8. Data for coal composition was sourced from the Queensland Coal Industry Review 2000-2001[19], The Australian Coal Yearbook 1996[20], Coal 1998[21], and Coal 2001[22].

Table 8 Weighted average composition of coals used at each of the major power station (as received basis)

Station	C (%)	H (%)	N (%)	S (%)	O (%)	Ash (%)	Total Moisture (%)	SE (HHV) (GJ/t)
Millmerran	41.7	3.5	0.6	0.4	6.6	32.3	15.0[a]	18.2
Callide A & B	52.0	2.6	0.7	0.1	11.1	17.9	15.5	20.0
Callide C	52.0	2.6	0.7	0.1	11.1	17.9	15.5	20.0
Collinsville	65.8	3.7	1.4	1.1	3.2	17.9	7.0	26.8
Gladstone	53.1	2.7	0.9	0.3	11.4	13.3	18.4	21.3
Swanbank A & B	58.2	4.5	1.1	0.5	8.1	16.4	11.3	25.3
Stanwell	66.5	3.7	1.4	0.6	4.0	14.2	9.6	27.1
Tarong	49.5	3.3	0.9	0.3	7.5	24.7	13.8	20.4
Tarong North	48.8	3.2	0.9	0.2	7.5	25.4	14.0	20.0

a) Estimated value

2.2.4 Natural gas

Natural gas supply to the Queensland power stations is via pipeline from the Cooper/Eromanga basin in South Australia. Energy consumption and associated emissions for extraction, processing, and transmission and distribution of gas are included. [23,24]

Fugitive emissions from all stages of processing are based on data given by the Australian Gas Association in its Greenhouse Challenge Collaborative Agreement with the Australian Federal Government[24], and from the National Greenhouse Gas Inventory Workbook for Fugitive Emissions.[17]

The CO_2 content of the raw natural gas (which is stripped to give <2% pipeline quality) is not reported for individual wells. For the present analysis, average Australian raw gas data is used - as reported by the Australian Greenhouse Gas Inventory. Generally, the raw gas from the North West Shelf and Bass Strait has low CO_2 contents (<3% v/v, from available proprietary data). However, the raw CO_2 content of wells in the Cooper-Eromanga basin (largest supplier of natural gas in Queensland) may be much higher (>15% v/v has been reported from some wells), which would significantly increase life cycle greenhouse gas emissions for gas based generation. This issue is the subject of a present study for the CCSD, and will require collaboration with the Australian gas industry.

However, as gas accounts for <2% of current Queensland generation (though this is likely to increase in the future), the overall effects on delivered electricity will be small. The main objective of a more accurate assessment is for one-on-one comparison of generation technologies using different energy sources. For gas, wellhead stripping is likely to become more significant.

The Queensland Government has recently implemented its “13% gas scheme” under which Queensland electricity retailers and other liable parties must source 13% of their electricity from gas-fired generation. Similar in principle to the Commonwealth’s “Mandatory Renewable Energy Target – (MRET)”, the scheme will involve the trading of gas electricity certificates in order to promote the development of gas fired electricity in Queensland. Qualifying fuels are natural gas, coal seam gas, LPG and waste gases associated with conventional petroleum refining. The program commenced in January 2005 and will run for 15 years.[25]

The pipeline composition of Queensland natural gas (as used in the analysis) is given in Table 9. Natural gas pipeline specifications are sourced from the National Greenhouse Gas Inventory (NGGIC) and Australian Gas Association.

Table 9 Average composition of NG in Queensland pipeline [28,10]

Component	Vol. %
Methane (CH_4)	88.8
Ethane (C_2H_6)	6.5
Propane (C_3H_8)	1.5
Butane (C_4H_{10})	0.5
Pentane (C_5H_{12})	0.1
Hexane (C_6H_{14})	0.1
CO_2	1.8
SE (MJ/Nm^3)	40.1

2.2.5 Other materials

A number of other materials are used in power generation, primarily in mining (ANFO and diesel), and for water treatment in cooling and boiler feedwater circuits. The materials used in this case study, and the location of manufacture, are listed in Table 10. Data was sourced from a range of company reports[11-13]. For the primary power stations, where specific chemical consumption data is not available, estimates based on other stations were used.

Table 10 Consumable used, manufacturing process and location

Consumable	Use	Location of manufacture
ANFO	Overburden blasting at open cut coal mines	Ammonium nitrate (produced from natural gas) based on the Incitec plant on Kooragang Island (Newcastle). Fuel oil produced at Queensland oil refinery in Brisbane. ANFO is mixed at a batching plant near the mine site.
Chlorine	For bacteria control in cooling towers	Produced via the chloralkali process at Lytton, with sodium hydroxide produced as a by-product.
Lime	Used for pH control in cooling circuits	Depending on the location of the power station, lime may be sourced from a range of kilns (eg East End).
Sodium hydroxide	Used for pH control in cooling and boiler feedwater circuits at power stations	Sodium hydroxide is produced in the chloralkali process at Lytton.
Sodium hypochlorite	Used for bacteria control in cooling circuits.	Produced at Lytton
Ammonia	Used in the steam condensate line to counter carbonic acid formation and to raise pH.	Ammonia production based on the Incitec plant on Kooragang Island (Newcastle)
Sulfuric acid	For pH control in cooling circuits.	Based on generic acid plant

2.2.6 Transportation

Transportation of coal and materials to power stations and other upstream operations (such as mines and chemical plants) is via road, rail or conveyor. Fuel consumption and emissions data for road and diesel rail transportation systems were sourced from the National Greenhouse Gas Inventory Workbook for Transport [16].

2.3 LCA considerations

There are a number of factors that may affect the LCA results. These are listed below.

- The contribution of CO2 emissions from wellhead stripping of natural gas has not been adequately quantified in this study due to the lack of data. While this will have only a small impact on the overall grid due to the small contribution of gas, it will have a significantly greater impact on GGE from individual gas based electricity generators.
- Power station efficiency data is based on annual average data for the station, and is not necessarily representative of the best possible efficiency at continuous rating. Individual station efficiency will be significantly affected by its position in the grid hierarchy.
- The accuracy of NPI data. Values may vary significantly between reporting periods. Also, aggregation of values on an enterprise basis affects accuracy in use.
- Allocation of solid wastes, in particular coal washery rejects and ashes. Many Queensland generators use higher ash coals produced concurrently with coal for export, which increases ash generation.

- Infrastructure (power stations, transmission lines etc) have not been included due to the small effect shown in previous studies – however, this factor is important when comparing technologies for individual plants, especially for renewable technologies.

2.4 Data quality

Estimated data accuracies for key items in the life cycle analysis are given in Table 11, together with the overall impacts on the GGE values.

Table 11 Data accuracies of key items

	Accuracy	Impact on energy	Impact on GGE
Electricity generation	± 2%	± 2%	± 2%
Coal mining	± 5%	< 0.1%	± 0.5%
Chemical production	± 10%	negligible	negligible
Transportation	± 10%	negligible	negligible

2.5 Allocation

All impacts are allocated to the functional unit of 1 MWh of electricity supplied from the Queensland transmission grid.

2.6 Impact assessment

Impact assessment is based on direct comparison of the following inventory values:

- Resource energy
- Fresh water
- GGE (CO_2-e)
- NO_x
- SO_x
- Particulates
- Solid waste
- NPI data for power generation, coal mining etc.

2.6.1 National Pollutant Inventory

The National Pollutant Inventory (NPI)[14] is an Internet database (http://www.npi.gov.au/) designed to provide the community, industry and government with information on the types and amounts of hazardous substances being emitted to the environment.

Australian industrial facilities using more than a specified amount of the substances listed on the NPI reporting list are required to estimate and report emissions of these substances annually.

Since 2002, the number of reportable substances has been extended from 36 to 90.

Table 12 lists these 90 substances as well as the associated reporting threshold, which is governed by the following conditions;

- The threshold for category 1 acids refers to the amount of the acid compound used (for example, in the case of hydrochloric acid, the threshold refers to the amount of hydrogen chloride used). This amount can be calculated as a factor of volume and concentration;
- The thresholds for total nitrogen and total phosphorus refer only to the amounts of those nitrogen and phosphorus compounds that give rise to nitrate/nitrite and phosphate ions respectively;
- The threshold for ammonia (total) refers to the total amount of both ammonia (NH_3) and the ammonium ion (NH_4^+) in solution;
- The threshold for chlorine includes the amount of hypochlorite and like substances used;
- The threshold for category 1 substances that are listed as (a metal) compounds refers to the total amount of the metal and its compounds used (for example, lead & compounds refers to lead and all compounds which incorporate lead);
- The threshold for phenol refers, at the discretion of the reporting facility, to either the total amount of phenolic compounds used or the total amount of phenol used.

Table 12 Listed Substances on the NPI from July 2001[14]

Substance	Category	Substance	Category
Acetaldehyde	1	Acetic acid (ethanoic acid)	1
Acetone	1	Acetonitrile	1
Acrylamide	1	Acrylic acid	1
Acrylonitrile (2-propenenitrile)	1	Ammonia (total)	1
Aniline (benzenamine)	1	Antimony & compounds	1
Arsenic & compounds	1,2b	Benzene	1
Benzene hexachloro- (HCB)	1	Beryllium & compounds	1,2b
Biphenyl (1,1-biphenyl)	1	Boron & compounds	1
1,3-Butadiene (vinyl ethylene)	1	Cadmium & compounds	1,2b
Carbon disulfide	1	Carbon monoxide	1,2a
Chlorine	1	Chlorine dioxide	1
Chloroethane (ethyl chloride)	1	Chloroform (trichloromethane)	1
Chlorophenols (di, tri, tetra)	1	Chromium (III) compounds	1,2b
Chromium (VI) compounds	1,2b	Cobalt & compounds	1
Copper & compounds	1,2b	Cumene (1-methylethylbenzene)	1

Substance	Category	Substance	Category
Cyanide (inorganic) compounds	1	Cyclohexane	1
1,2-Dibromoethane	1	Dibutyl phthalate	1
1,2-Dichloroethane	1	Dichloromethane	1
Ethanol	1	2-Ethoxyethanol	1
2-Ethoxyethanol acetate	1	Ethyl acetate	1
Ethyl butyl ketone	1	Ethylbenzene	1
Ethylene glycol (1,2-ethanediol)	1	Ethylene oxide	1
Di-(2-Ethylhexyl) phthalate (DEHP)	1	Fluoride compounds	1,2a
Formaldehyde (methyl aldehyde)	1	Glutaraldehyde	1
n-Hexane	1	Hydrochloric acid	1,2a
Hydrogen sulfide	1	Lead & compounds	1,2b
Magnesium oxide fume	1,2b	Manganese & compounds	1
Mercury & compounds	1,2b	Methanol	1
2-Methoxyethanol	1	2-Methoxyethanol acetate	1
Methyl ethyl ketone	1	Methyl isobutyl ketone	1
Methyl methacrylate	1	4,4'-Methylene-bis(2-chloroaniline) (MOCA)	1
Methylenebis (phenylisocyanate)	1	Nickel & compounds	1,2b
Nickel carbonyl	1,2b	Nickel subsulfide	1,2b
Nitric acid	1	Organo-tin compounds	1
Oxides of nitrogen	2a	Particulate Matter 10.0 um (PM10)	2a
Phenol	1	Phosphoric acid	1
Polychlorinated dioxins and furans	2b	Polycyclic aromatic hydrocarbons	2a
Selenium & compounds	1	Styrene (ethenylbenzene)	1
Sulfur dioxide	1,2a	Sulfuric acid	1
1,1,1,2-Tetrachloroethane	1	Tetrachloroethylene	1
Toluene (methylbenzene)	1	Toluene-2,4-diisocyanate	1
Total nitrogen	3 (15 t/yr)	Total phosphorus	3 (3 t/yr)
Total volatile organic compounds	1a,2a	1,1,2-Trichloroethane	1
Trichloroethylene	1	Vinyl chloride monomer	1
Xylenes (individual or mixed isomers)	1	Zinc and compounds	1

The revised category thresholds are shown in Table 13.

Table 13 Category threshold definitions

Category	Description
1	Consumption of 10 t per year
1a	Consumption of 25 t per year, or a design capacity of 25 kt for bulk storage facilities
2a	Consumption of 400 t per year of fuel or 1 t of fuel per hour at any time within the period
2b	Consumption of 2,000 t per year of fuel, or 60,000 MWh, or at any time within the period, a consumption of electricity at a rate of 20 MW.
3	Special case (emission based)

3 RESULTS

3.1 Energy and raw material flows

Resource consumption per MWh of power generated from the Queensland transmission grid is shown in Table 14. It should be noted that these resources represent consumables used directly or indirectly for the generation of electricity on the grid. Infrastructure (power stations, transmission lines etc) have not been included, and thus resources for materials of construction are not included.

Table 14 Resource consumption per MWh of electricity from the Queensland transmission grid

Resource	Amount	Unit	Comment
Coal	0.501	t	Coal fired boiler fuel
Crude oil	0.083	GJ	For coal-fired boiler start-up, gas turbine peaking stations and transport fuel
Limestone	0.00015	t	Lime production for pH adjustment of power station cooling water
NG	0.150	GJ	Gas fired peaking stations and ammonia/ammonium nitrate production
Fresh water	1.83	m^3	Primarily for power station evaporative cooling and boiler feedwater

The largest consumables per MWh of power produced by the Queensland grid are black coal (480 kg) and fresh water (1,815 kg). Chemical feedstocks, natural gas and petroleum based fuels and biomass are consumed at comparatively low rates, though it should be noted that the share of natural gas increased from 0.076 GJ in 2001 to 0.15 GJ in 2004, representing a 100% increase. This is encouraging, considering the governments push for the 13% gas scheme.

Although not an actual resource, it should also be noted that hydro and other renewables contribute 17.0 kWh per MWh of electricity supplied by the electricity grid (ie. 1.7%).

3.2 Impact assessment values

The total for electricity sent-out from power stations, and electricity available to the transmission and distribution grids are shown in Table 15. This reflects the losses due to transmission and distribution which are 5.3% and 5.82% respectively.

Table 15 - Total electricity flow through Queensland grid

Total sent out electricity (GWh)	Electricity available from transmission grid (GWh)	Electricity available from distribution grid (GWh)
49,480	46,866	44,138

A summary of the results for the production of 1 MWh of electricity is shown in

Table 16.

Table 16 Impact assessment values for 1 MWh of Queensland grid electricity (no interstate purchases)

Parameter	Transmission grid	Distribution grid	Comment
Inputs			
Resource energy (GJ)	10.91	11.58	97.3% coal, 0.76% crude oil, 1.37% NG
Fresh water (m^3)	1.83	1.95	Primarily for evaporative cooling
Outputs			
GGE (kg CO_2-e)	983	1044	97.7% from power stations, 1.96% from coal mining
NOx (kg)	3.61	3.83	98.6% from fossil fuel power generation
SOx (kg)	3.01	3.20	99.8% from power generation
Particulates (kg)	0.76	0.80	56.0% from open cut coal mining, 44.0% from power generation
Solid waste (kg)	94.8	100.6	100% from power generation

The difference between 1 MWh of electricity from the transmission and distribution grids is an increase of 5.82% (average) due to losses in the distribution system.

In summary:

- The resource energy consumption for the Queensland transmission grid is dominated by coal (97.3%), with only small contributions from natural gas, and oil.
- Fresh water is consumed primarily by the inland coal fired power stations for condenser cooling. Every MWh of electricity from the Queensland transmission grid consumes, on average, 1.83 m^3 of fresh water. This equates to a total consumption of around 86 GL per annum.

- Greenhouse gas emissions are dominated by emissions from coal fired power stations (97.7%), followed by coal mining (2.0%).
- The majority of NO_x, SO_x and solid waste emissions are from coal fired power stations. The main sources of particulate emissions are open cut coal mines which are responsible for over 50% of the total amount.

When the LCA results are projected out to a Queensland basis, an assessment can be made on the contribution of power generation (including associated coal mining, transportation, chemical production etc) to the State total. Table 17 shows the projected emissions from the Queensland grid, with comparison to the State total.

Table 17 Projected impacts from Queensland power generation compared to State total[14,26,27,28,29]

Parameter	Transmission grid 2003-4 (per MWh)	Distribution grid 2003-04 (per MWh)	Total from transmission grid 2003-04 (per annum)	Total QLD - all sources (per annum)	% of State
Resource energy	10.91 GJ	11.56 GJ	511.1 PJ	1,164 PJ	43.9
Fresh water[3]	1.83 m^3	1.95 m^3	85.9 GL	4,711 GL[4]	1.8
GGE[2]	983 kg CO_2-e	1044 kg CO_2-e	46.0 Mt	145 Mt	31.7
NO_x[1]	3.61 kg	3.83 kg	168 kt	320 kt	52.5
SO_x[1]	3.01 kg	3.2 kg	141 kt	430kt	32.8
Particulates[1]	0.76 kg	0.80 kg	35.4 kt	160 kt	22.1

1. 2003-04 data (National Pollutant Inventory website)
2. 2002 data as is most recent
3. Assumed to remain at 2% as new data is not available
4. 2000/2001 data (most recent)

The comparison shows that a significant portion of all environmental impacts in Queensland, are associated with the generation of electricity. The notable exception is that of water, which is dominated by agricultural use.

3.2.1 Point source emissions

The point source greenhouse gas, NO_x, SO_x, and particulate emissions are shown in Figure 2 to Figure 5, per MWh of electricity from the Queensland transmission grid. The data is presented with the top bar graph showing the contribution from each power station to the total emission resulting from the transmission of 1 MWh from the grid, and the bottom graph showing the rate of emission per MWh generated at that facility alone. The pie graph indicates the percentage of total emission that each power station is responsible for.

For greenhouse gas emissions (Figure 2), the primary contributors are Tarong, Stanwell, Gladstone, Callide C, Callide B, and Millmerran (these closely follow the grid contributions). Underground coal mines, smaller power stations, natural gas and oil processes contribute to a significantly lesser extent.

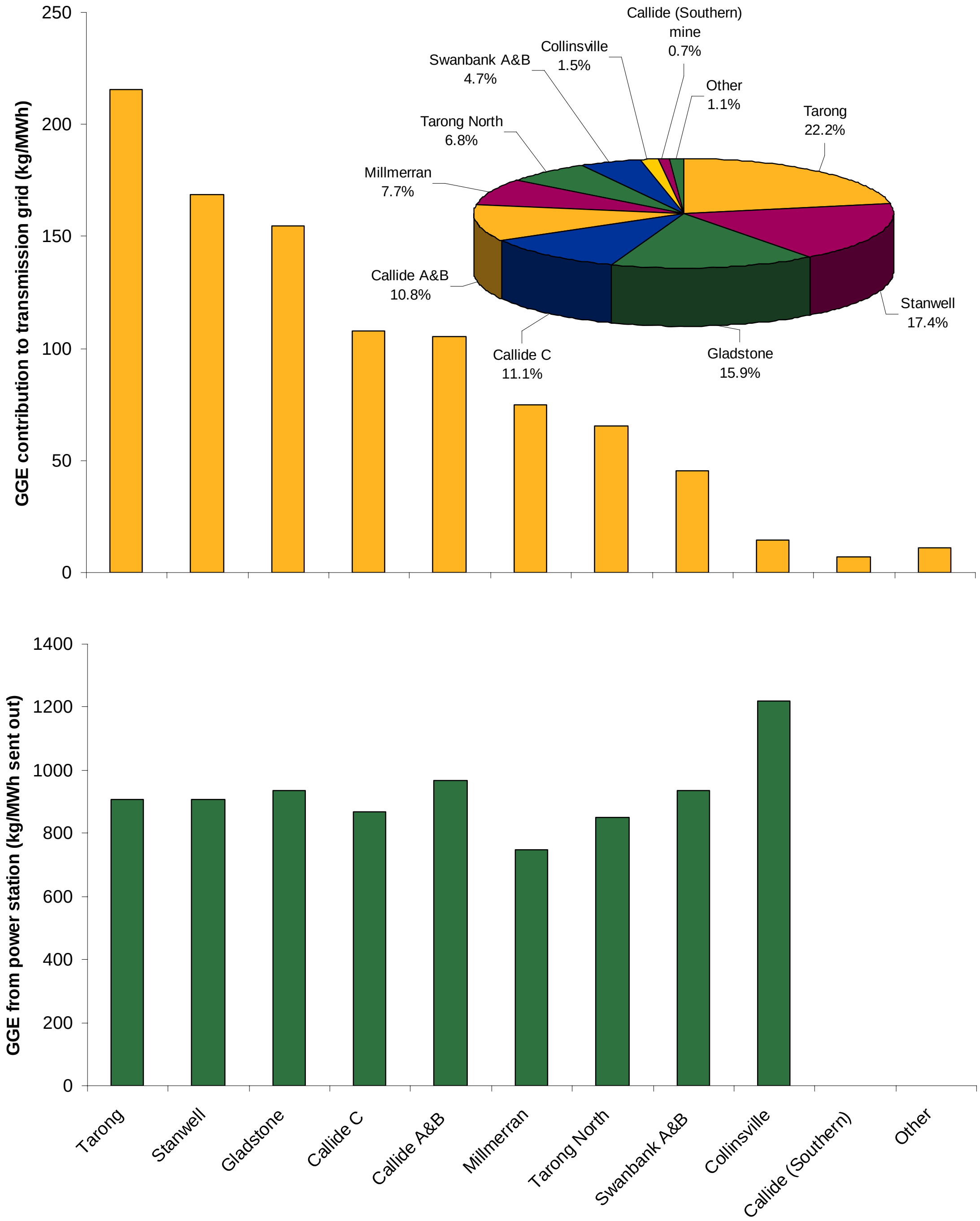

Figure 2 Breakdown of GGE per MWh of electricity from the Queensland transmission grid

NOx emissions (Figure 3) are primarily from the large coal fired power stations with Tarong, Gladstone, Stanwell and Callide B the major contributors. Smaller contributions are from other power stations, coal mining and transportation.

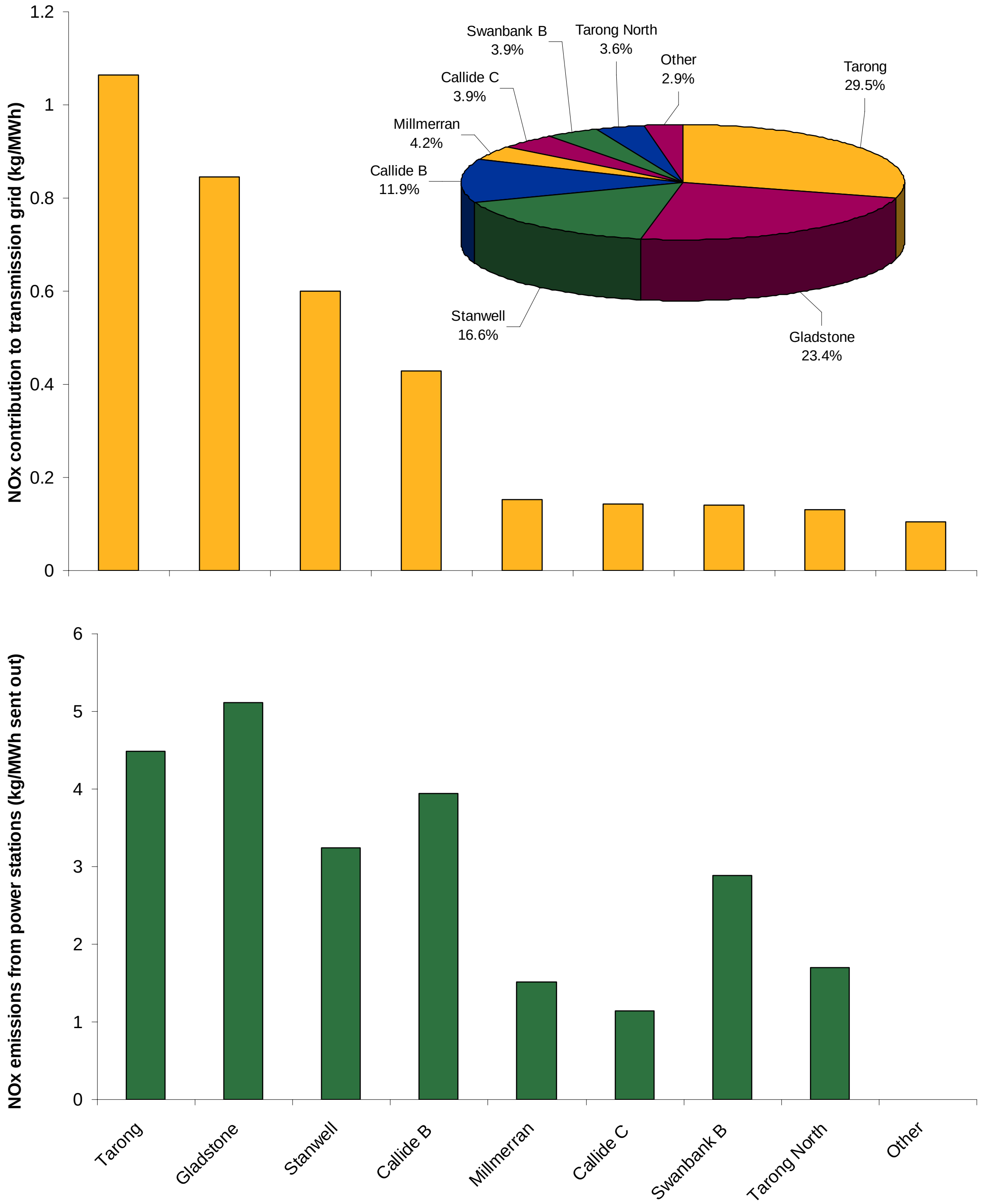

Figure 3 Breakdown of NO_x per MWh of electricity from the Queensland transmission grid

SO_x emissions (Figure 4) are again primarily from the large coal fired power stations with Stanwell, Tarong, Gladstone, Millmerran and Swanbank B the major contributors. SO_x emissions from sources other than coal-fired power stations are insignificant.

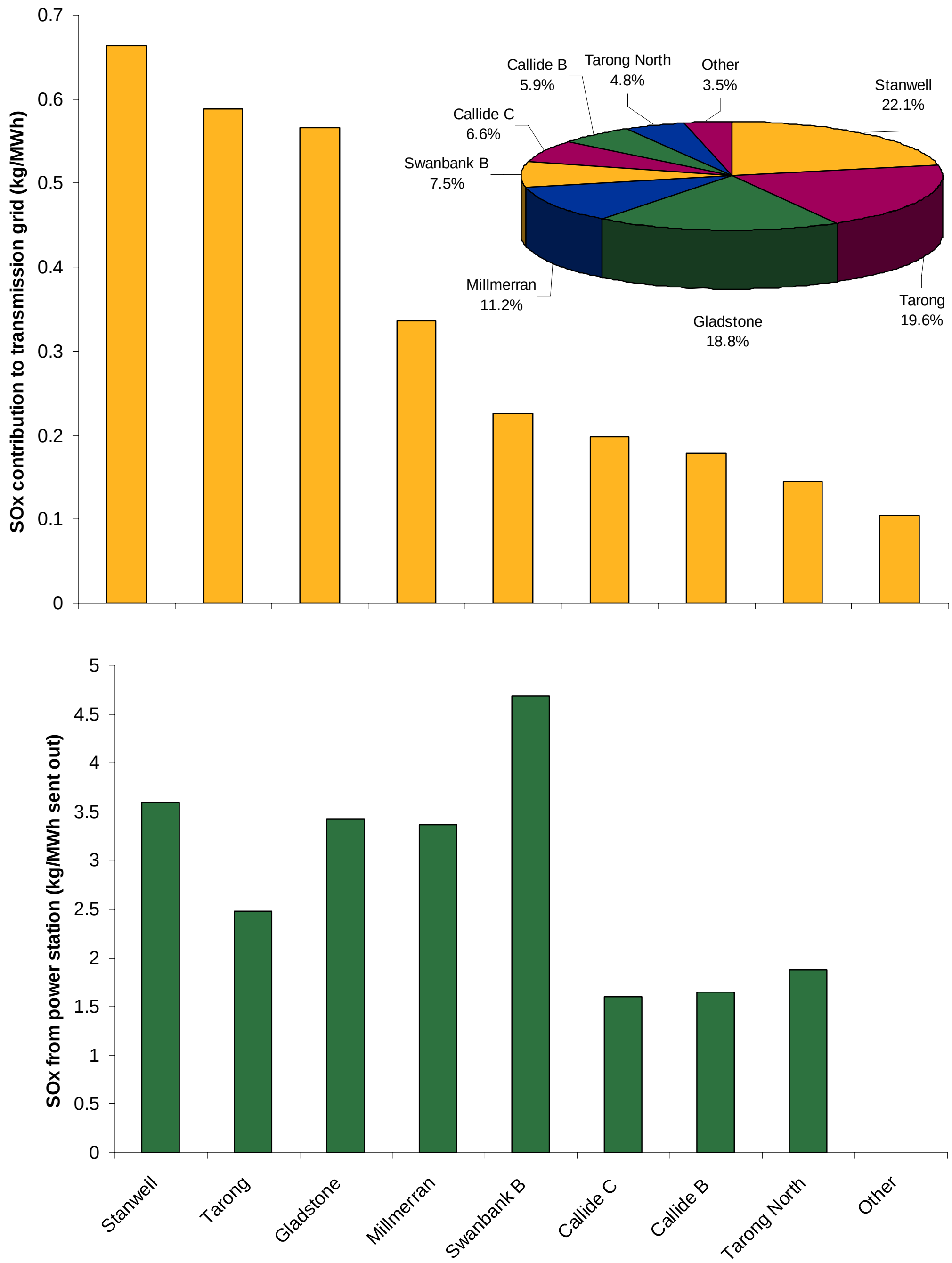

Figure 4 Breakdown of SO_x per MWh of electricity from the Queensland transmission grid

For particulates (Figure 5), four of the top five emitters are open cut coal mines. Large coal fired power stations, especially those with electrostatic precipitators (Tarong, Callide B, and Stanwell), are significant contributors to particulate emissions per MWh of electricity from the Queensland transmission grid. Tarong is the highest contributor due to the consumption of high ash coals and because it employs ESP rather than fabric filters as a means for reducing particulate emissions.

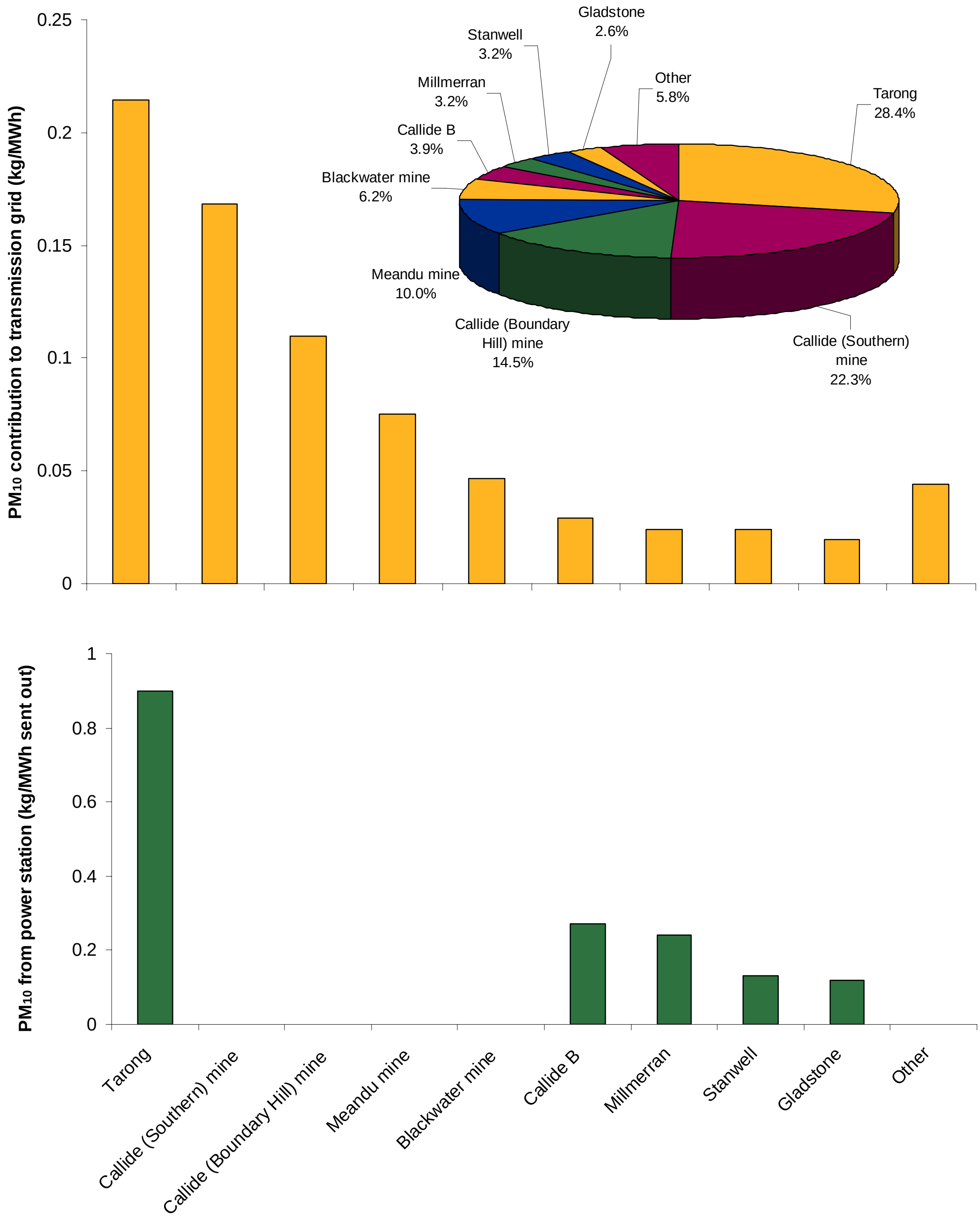

Figure 5 Breakdown of particulate emissions per MWh of electricity from the Queensland transmission grid

Figure 6 shows a breakdown of the ash generated per MWh of electricity from the Queensland transmission grid (no interstate transfers). The top of the orange bar represents the total ash generated by the power station (per MWh from Queensland grid) while the green bar represents the proportion of the coal ash utilised.

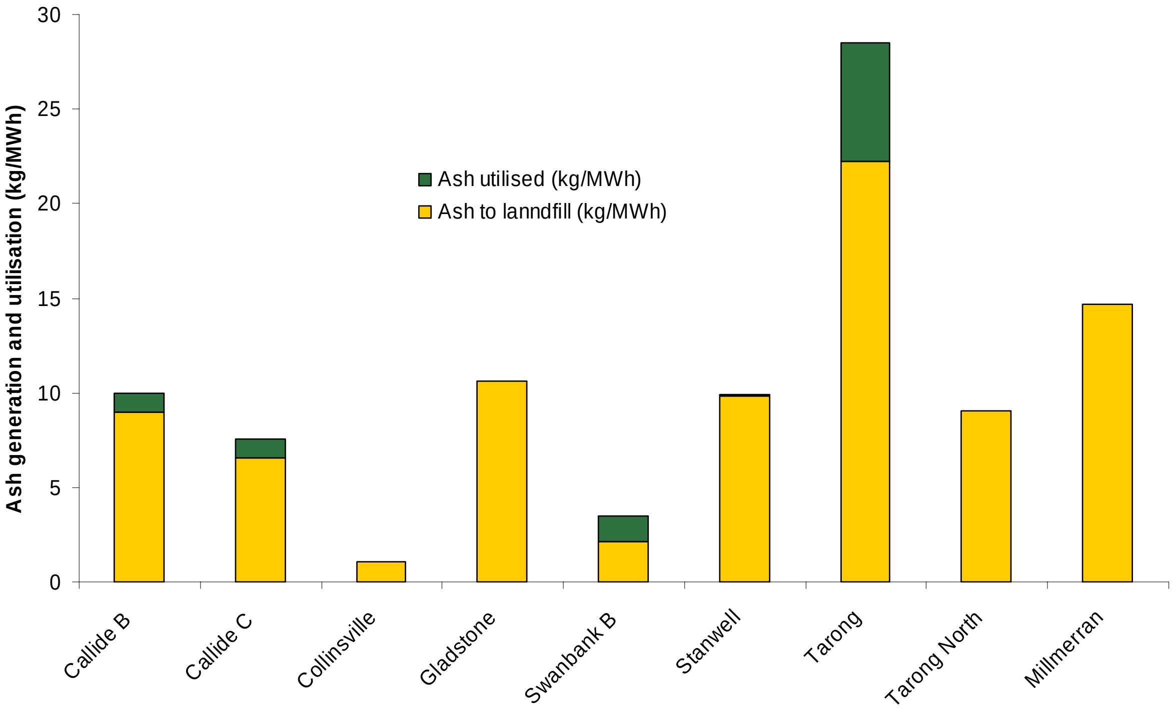

Figure 6 Breakdown of ash generation and utilisation per MWh of electricity from the Queensland transmission grid

The rate of utilisation of coal ash (fly and bottom ash) in Queensland is currently greater than 10%. This is equal to a utilisation rate of approximately 9.6 kg/MWh, or an annual use of 451,000 tonnes of ash from over 4.44 million tonnes of ash produced.

It is important to note that not all stations reported their ash utilisation. This includes Millmerran, Gladstone and Collinsville. The ash produced by these power stations is included in the total, and should some of this ash be used, the utilisation rate would be greater.

The percentage of power station generated ash utilised in Australia in 2003 was 18.8%. The percentage of ash used in cement in Queensland is unknown. However, on a national basis, the quantity of fly ash sold in cementitious product was approximately 1.42 Mt (10.9% of ash generated), and sales are increasing (Ash Development Association of Australia, 2003)[30].

3.2.2 National Pollutant Inventory

The National Pollutant Inventory (NPI) data per MWh of electricity from the Queensland transmission grid are given in Table 18, Table 19 and Table 20, reporting emissions to air, water and land, respectively. The results are given on a per MWh basis and on a total tonnes per annum basis.

Table 18 NPI emissions to air per MWh of electricity from the Queensland transmission grid

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
1,1,2-trichloroethane	$4.169x10^{-11}$	0.002	1 coal mine
1,3-butadiene (vinyl ethylene)	$8.100\ x10^{-11}$	0.004	Oil refining
Acetone	$1.000\ x10^{-12}$	~ 0	Oil refining
Ammonia (total)	$2.879\ x10^{-08}$	1.35	1 power station, oil refining
Antimony & compounds	$3.200\ x10^{-11}$	0.002	1 coal mine
Arsenic & compounds	$1.420\ x10^{-08}$	0.666	18 power stations, 9 coal mines, oil refining
Benzene	$9.754\ x10^{-09}$	0.457	3 power stations, 3 coal mines, oil refining
Beryllium & compounds	$3.107\ x10^{-09}$	0.146	10 power stations, 2 coal mines
Boron & compounds	$3.824\ x10^{-06}$	179	7 power stations, 5 coal mines
Cadmium & compounds	$2.509\ x10^{-09}$	0.118	18 power stations, 6 coal mines, oil refining
Carbon disulfide	$1.000\ x10^{-14}$	~ 0	1 power station
Carbon monoxide	$1.601\ x10^{-4}$	7,500	23 power stations, 15 coal mines
Chlorine	$2.370\ x10^{-10}$	0.011	4 power stations
Chromium (III) compounds	$3.198\ x10^{-08}$	1.50	14 power stations, 6 coal mines
Chromium (VI) compounds	$5.574\ x10^{-08}$	2.61	18 power stations, 6 coal mines, oil refining
Cobalt & compounds	$1.456\ x10^{-08}$	0.682	10 power stations, 11 coal mines, oil refining
Copper & compounds	$3.622\ x10^{-08}$	1.70	13 power stations, 6 coal mines
Cumene (1-methylethylbenzene)	$4.460\ x10^{-10}$	0.021	2 power stations, 1 coal mine
Cyanide (inorganic) compounds	$1.500\ x10^{-13}$	~ 0	1 power station
Cyclohexane	$3.490\ x10^{-10}$	0.016	Oil refining
Ethylbenzene	$1.330\ x10^{-10}$	0.006	3 power stations, oil refining
Fluoride compounds	$3.775\ x10^{-05}$	1,770	8 power stations, 1 coal mine
Fluorides	$3.291\ x10^{-07}$	15.4	8 power stations, 14 coal mines, oil refining
Formaldehyde (methyl aldehyde)	$5.180\ x10^{-10}$	0.024	1 power station, oil refining
Hydrochloric acid	$1.237\ x10^{-4}$	5,799	9 power stations
Lead & compounds	$5.396\ x10^{-08}$	2.53	21 power stations, 12 coalimes, oil refining
Magnesium oxide fume	$6.500\ x10^{-13}$	~ 0	1 power station
Manganese & compounds	$1.212\ x10^{-07}$	5.68	7 power stations, 7 coal mines
Mercury & compounds	$6.746\ x10^{-09}$	0.316	20 power stations, 6 coal mines, oil refining
Methanol	$1.000\ x10^{-12}$	~ 0	Oil refining
Methyl ethyl ketone	$1.263\ x10^{-08}$	0.592	1 power station, oil refining

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
Methyl isobutyl ketone	1.000×10^{-14}	~ 0	1 power station
n-hexane	4.200×10^{-11}	0.002	1 power station
Nickel & compounds	3.586×10^{-08}	1.68	14 power stations, 6 coal mines
Oxides of nitrogen	3.590×10^{-03}	168,000	23 power stations, 15 coal mines
Particulate matter 10.0 um	7.551×10^{-04}	35,400	23 power stations, 15 coal mines
Phosphorous (total)	2.100×10^{-11}	0.001	Oil refining
Polycyclic aromatic hydrocarbons	7.168×10^{-09}	0.336	16 power stations, 4 coal mines, oil refining
Selenium & compounds	1.208×10^{-11}	~ 0	1 power station, 1 coal mine
Styrene (ethenylbenzene)	1.000×10^{-12}	~ 0	Oil refining
Sulfur dioxide	3.007×10^{-3}	141,000	22 power stations, 14 coal mines
Sulfuric acid	3.325×10^{-05}	1,558	9 power stations
Tetrachloroethylene	2.000×10^{-14}	~ 0	1 power station
Toluene (methylbenzene)	5.730×10^{-08}	2.69	2 power stations, 2 coal mines, oil refining
Total nitrogen	3.779×10^{-09}	0.177	Oil refining
Total volatile organic compounds	1.663×10^{-05}	779	16 power stations, 9 coal mines
Xylenes (individual or mixed isomers)	4.045×10^{-08}	1.90	4 power stations, 5 coal mines, oil refining
Zinc & compounds	6.015×10^{-08}	2.82	8 power stations, 7 coal mines, oil refining

Table 19 NPI emissions to water per MWh of electricity from the Queensland transmission grid

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
Ammonia (total)	4.000×10^{-14}	~ 0	1 power station
Arsenic & compounds	6.366×10^{-09}	0.298	7 power stations, 4 coal mines
Beryllium & compounds	1.110×10^{-10}	0.005	2 power stations
Boron & compounds	8.476×10^{-08}	3.97	5 power stations
Cadmium & compounds	1.650×10^{-10}	0.008	3 power stations, 1 coal mine
Chlorine	1.870×10^{-10}	0.009	1 power station
Chromium (III) compounds	4.081×10^{-09}	0.191	5 power stations
Chromium (VI) compounds	1.685×10^{-09}	0.079	2 power stations, 5 coal mines
Cobalt & compounds	7.570×10^{-10}	0.035	2 power stations, 3 coal mines
Copper & compounds	5.839×10^{-09}	0.274	4 power stations
Fluoride compounds	1.561×10^{-07}	7.32	4 power stations
Fluorides	2.782×10^{-08}	1.3	2 power stations, 3 coal mines
Lead & compounds	2.172×10^{-09}	0.102	4 power stations, 5 coal mines
Manganese & compounds	1.117×10^{-07}	5.23	3 power stations
Mercury & compounds	3.300×10^{-11}	0.002	4 power stations, 1 coal mine
Nickel & compounds	2.001×10^{-09}	0.094	4 power stations
Sulfuric acid	3.053×10^{-08}	1.43	1 sulfuric acid plant
Total nitrogen	1.000×10^{-11}	~ 0	1 power station, 1 mine
Total phosphorus	9.000×10^{-14}	~ 0	1 power station
Zinc & compounds	1.168×10^{-08}	0.547	4 power stations

Table 20 NPI emissions to land per MWh of electricity from the Queensland transmission grid

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
Arsenic & compounds	2.000×10^{-12}	~ 0	2 coal mines
Benzene	1.260×10^{-10}	0.006	1 coal mine
Chromium (VI) compounds	2.100×10^{-11}	0.001	2 coal mines
Fluorides	1.000×10^{-14}	~ 0	1 coal mine
Lead & compounds	2.000×10^{-11}	0.001	2 coal mines
Polycyclic aromatic hydrocarbons	4.100×10^{-11}	0.002	1 coal mine
Xylenes (individual or mixed isomers)	1.510×10^{-09}	0.071	1 coal mine

The results show that per MWh of electricity supplied by the Queensland transmission grid, small amounts of most emission types are emitted; from the order of micrograms (eg methanol to air, arsenic & compounds to land) up to kilograms (eg NO_x, SO_x). When these emissions are converted to a per annum basis, the quantities range from ~0.5g to 168,000 tonnes, (oxides of nitrogen to air).

Of the reported emissions in Queensland, power generation represents a significant proportion for some emission types. For example, the total reported NO_x emissions in Queensland on the NPI for the year ending June 2004 were approximately 320,000 tonnes. The present study has shown that emissions of NO_x associated with power generation from the Queensland transmission grid of the same time period were 168,000 tonnes or approximately 52.5% of the total reported emissions. NPI data currently available shows some inconsistencies when compared with other data sources such as company environment reports, and does not cover all sites (ie many coal mines have not contributed NPI data), though this may be due to threshold limits.

3.3 System displacement credits

A potential displacement credit has been calculated for the present utilisation of coal ash as a cement extender (assumes 11.34% is used as cement extender) and also for the scenario assuming that 100% of the coal ash produced is used as a cement extender (see Table 21).

Table 21 Displacement credits for coal ash utilisation as a cement extender for 1 MWh of electricity from the Queensland transmission grid (no interstate transfers)

Parameter	0% displacement	10.16% (current displacement assuming all ash to cement)	100% (maximum potential displacement)
Resource energy (GJ)	10.91	10.84	10.37
GGE (kg CO_2-e)	983	973	888
NO_x (kg)	3.61	3.59	3.43
SO_x (kg)	3.01	3.00	2.97

Table 21 shows that with current ash utilisation (assuming as cement extender) there is a greenhouse gas saving of 1.0%. If the ash utilisation was increased to 100% there would be a potential saving in greenhouse gas emissions of 9.6% overall, or 8.7% from current utilisation rates. This outcome makes this avenue for greenhouse gas mitigation very attractive, though it should be noted that not all ash will be suitable for cement extender, and the cement market may not be large enough to enable the use of all ash produced.[31]

4 COMPARISON TO PREVIOUS STUDY

These results are the first set to be compared to the original Life Cycle Analysis completed for the 2001 financial year. The results for the inputs and outputs for both periods are shown below, as well as the change in the 2004 numbers as a percentage of those from 2001.

Table 22 Comparison of inputs and outputs from the Queensland electricity grid (comparisons with previous study)

Parameter	2001 Transmission grid	2001 Distribution grid	2004 Transmission grid	2004 Distribution grid	Difference [a] (%)
Inputs					
Resource energy (GJ)	11.41	12.08	10.91	11.58	- 4.4%
Fresh water (m^3)	1.74	1.84	1.83	1.95	+ 4.9%
Outputs					
GGE (kg CO_2-e)	1028	1088	983	1044	- 4.4%
NO_X (kg)	4.14	4.41	3.61	3.83	- 12.8%
SO_X (kg)	2.96	3.13	3.01	3.20	+ 1.7%
Particulates (kg)	0.77	0.81	0.76	0.80	- 1.3%
Solid waste (kg)	87.8	92.9	84.9	90.1	- 3.3%

[a] Note that the differential is based on the per MWh electricity from transmission grid

Key findings include:

- Overall system efficiency has improved since 2001, shown by the decrease in resource energy consumption per MWh output. This is due to the retirement of some of the older generating units in conjunction with the addition of Millmerran and Tarong North which exhibit higher efficiencies.
- Water consumption was seen to increase over the past three years on a MWh basis. This was due to Stanwell reporting water consumption at a much higher level in this period. As Stanwell is a major generator, this had a significant effect on the total water consumption of the grid.
- The grid has improved its greenhouse intensity on a per MWh basis, reducing from 1028 kg/MWh in 2001 to 983 kg/MWh in 2004. Greenhouse emission intensity decreased in line with the decrease in required energy resource per unit of output. It is expected that if the government is successful with its program to increase gas generated electricity in the state, that greenhouse gas intensity will decrease further.
- NO_x emissions from power generation have a greater than 50% share in NO_x emissions for the entire state. However, this percentage has decreased since 2001 from 54.8% to 52.8% of the state total. There has been a considerable decrease in NO_x emissions per MWh of output over this time. This reduction (12.8%) in NO_x emission intensity has been the result of the replacement of old power stations with new, lower NO_x emitting stations. Additionally, Callide power plant has managed to decrease its emission level by 62% over this period, according to the NPI.
- Electricity generation made a considerably larger contribution to the state total for SO_x emissions as a percentage this year than it did in 2001, although the SO_x intensity of the grid only increased by 1.7%. This is considered an insignificant increase.

- The majority of the particulate emissions for the Queensland grid are due to coal mining operations. Tarong became the largest source of PM_{10} emissions in this period, with a 50% increase in specific PM_{10} emissions relative to 2001. This was offset by reductions from other parts of the lifecycle, resulting in an overall decrease in emissions per MWh.
- Current details on transmission and distribution losses were unavailable. The present study used the 1997 value published by the ESAA of 5.3% for transmission loss. The current value for distribution loss was obtained from the ESAA 2003 (1 year previous to this study) and was 5.82%, (compared to 5.5% in 2001).

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