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A LIFE CYCLE ASSESSMENT OF THE QUEENSLAND ELECTRICITY GRID

(Year Ending June 2001)

TECHNOLOGY ASSESSMENT REPORT 26

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EXECUTIVE SUMMARY

This report gives results for a life cycle analysis (LCA) for the supply of 1 MWh of electricity from the Queensland grid based on YEJ 2001, and a generation capacity of ~8,800 MW. This report is part of a series of LCA studies of the Australian State grids, which are being undertaken to provide benchmark data sets for future studies by the CCSD. 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). The study includes a range of indicators including resource energy and fresh water consumption, greenhouse gas emissions (GGEs), NO_x, SO_x, particulates and solid waste emissions, and a range of substances sourced from the National Pollutant Inventory (NPI) database. 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 on both a MWh and 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	Transmission grid 2000-01 (per MWh)	Distribution grid 2000-01 (per MWh)	Total from Qld grid 2001-01 (per annum)	Total Qld - all sources (per annum)	% of State
Resource energy	11.4 GJ	12.08 GJ	435.1 PJ	1,040[1] PJ	41.8
Fresh water	1.74 m3	1.84 m3	66.2 GL	3,242[2] GL	2.0
GGE	1028 kg CO2-e	1088 kg CO2-e	39.2 Mt	112.01 Mt	35.0
NO_x	4.14 kg	4.41 kg	159 kt	290.0[3] kt	54.8
SO_x	2.96 kg	3.13 kg	113 kt	470.0[3] kt	24.0
Particulates	0.77 kg	0.81 kg	29.3 kt	152.7[3] kt	19.1

1. Projected from 1998 data (National Greenhouse Gas Inventory, Queensland State of the Environment 1999)
2. Annual human water consumption (Queensland State of the Environment 1999). Approximately 80% of water withdrawn from storage is used agriculture.
3. 2000-01 data (National Pollutant Inventory website)

Key findings are:

- On a state-wide basis, activities associated with grid 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 hydro and agriculture).
- The grid also accounts for significant amount of other emissions, particularly GGE and NO_x.

- SO_x emissions from power generation have a smaller contribution to state totals due to the large amount of SO_x emitted from the Mt Isa Copper Smelter, and to a lesser extent to the low sulphur content of most Queensland coals. Likewise for particulates, power station stack particulate emissions are disproportionally low (despite precipitation issues at some stations) due to the predominance of large open cut mines - this effect is increased by the proportion of export coal produced.
- On a MWh basis, and compared to other state grids completed in this series (Victoria and NSW), Queensland electricity has:
  - the highest NO_x emissions (200% of Victoria)
  - the largest fresh water consumption
  - higher greenhouse gas emissions and resource energy consumption than NSW, but significantly lower than Victoria
  - SO_x emissions slightly larger than Victoria, but considerably less than NSW,
  - particulate emissions (power stations only) that are similar to those for Victoria, but 400% greater than for NSW.
- Current details on transmission losses were losses were unavailable, and the present study used the 1997 value published by the ESAA of 5.3%. The current value for distribution losses was also obtained from the ESAA and was 5.5%.
- Overall, the greenhouse gas emission values agree closely with those from the Australian Greenhouse Office Greenhouse Challenge Workbook. This is to be expected, as most GGE for coal-based generation occur from combustion, which reduces the effects of different methodologies (note, LCA is based on a systems basis and includes upstream processes, whereas AGO reports on an enterprise basis). Note, the predominance of combustion emissions (ie "burner-tip") does not always apply for other energy sources, eg hydro or natural gas (the latter being more significant in Queensland.
- The LCA methodology, particularly its approaches to allocation and assumptions, has enabled a more transparent data set than has been available from previous studies. A particular outcome has been the disaggregation of emissions from each of the major power stations, and data reconciliation taking into account generation efficiency, fuel use, fuel composition etc.

There were a number of areas identified for further investigation, and required to improve on the quality and the relevance of the analysis:

- Improved data is required (disaggregated) for the Queensland natural gas system (wellhead CO2 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.
- Errors and omissions in the National Pollutant Inventory (NPI) data need to be resolved before the next analysis.
- Details on transmission and distribution losses is required.

- Improvement to the assessment methodology by incorporation of economics and improved impact assessment criteria will be essential for process improvement targeting, incremental technologies and the assessment of future technology options/energy scenarios.
- Additional case studies to assess the impact of future power generation scenarios for Queensland - starting with the addition of proposed power stations and the proposals for extensive utilisation of coal bed methane (and in-situ gasification), and latter advanced power generation technologies with combination of capture and sequestration, and intra-industry integration.

1 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 connected generators is summarised in Table 1 below (includes co-generation and renewables). The Queensland generation capacity is the second largest in Australia, with a total installed capacity of 9,865 MW (June 2001).

Table 1 Power generation capacity of Australian States (June 2001)[1]

State	Principal plant (MW)	Non-grid generators (MW)	Cogeneration (MW)	Total (MW)	% of total
NSW & ACT	12,197	648	101	12,946	27.0
Qld	8,816	907	142	9,865	20.5
VIC	7,864	589	225	8,678	18.1
SA	3,137	213	30	3,380	7.0
WA	3,315	1,859	911	6,085	12.7
NT	495	173	106	774	1.6
Tas	2,508	16	16	2,540	5.3
SMHEA	3,756	-	-	3,756	7.8
Total	42,088	4,405	1531	48,024	100

1.2 Queensland grid[1,2,3]

In 2001, a total of 42,250 GWh of electricity was sent out from the Queensland 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)	Comm.year	Fuel	GWh sent out (2000-01)	GWh sent out (%QLD)
Tarong	Tarong Energy	Pf boiler	1400	1984-86	Coal	10,411	25.8
Gladstone	Comalco/NRG	Pf boiler	1680	1976-81	Coal	9,886	24.2
Stanwell	Stanwell Corporation	Pf boiler	1400	1993-96	Oil	9,325	23.1
Callide A	CS Energy	Pf boiler	120	1998	Coal	5,563	14.1
Callide B	CS Energy	Pf boiler	700	1988/89	Coal		
Swanbank A	CS Energy	Pf boiler	408	1966-69	Coal	3,102	7.8
Swanbank B	CS Energy	Pf boiler	500	1970-73	Coal[1]		
Collinsville	CS Energy	Pf boiler	185	1998	Coal	532	1.3
Kareeya	Stanwell Corporation	Hydro	72	1957/59	Hydro	445	1.1
Callide Power Plant	CS Energy/ Intergen	Pf boiler		2001	Coal	435	1.1
Barron Gorge	Stanwell Corporation	Hydro		1963	Coal	265	0.7
Barcaldine	Energy Equity	CCGT	57	1996	NG	155	0.4
Roma	Origin Energy		74	1999	Oil	86	0.2
Mt Stuart	AES Transpower	OCGT	277	1998	Oil	30	0
Middle Ridge	CS Energy	OCGT	56	1970	Oil	0	0
Mackay	Stanwell Corporation	OCGT	34	1976	Oil	0.5	0
Oakey	Oakey Power Ventures	OCGT	305	1999	Coal	9	0
Swanbank C	CS Energy	OCGT	26	1973	NG	0.06	0
Swanbank D	CS Energy	OCGT	37	1999	NG	0.9	0
Wivenhoe	Tarong Energy	Pumped hydro	500	1984	Hydro	0	0
Yabulu	Transfield Holdings	OCGT	165	1999	NG	3.1	0
					Total	42,247	99.8

1. Coal seam methane
2. Data is estimated based on capacity and assumed capacity factor

Factors also contributing to the LCA are losses from the high and low voltage transmission and distribution grids, with the distribution grid having the greatest influence. Powerlink and TransÉnergie operate the high voltage transmission grid. The low voltage distribution grid is controlled by Energex (Metropolitan) and Ergon Energy (Regional). 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 CS Energy, Stanwell Corporation, Tarong Energy Corporation, Enertrade, Origin Energy, Intergen and Callide Power Trading. There is also a grid interconnection with New South Wales.

1.3.1 Enertrade[4]

Barcaldine power station (1996)

Barcaldine is a combined cycle power station located 750 km west of Rockhampton and is owned and operated by Energy Equity Corporation. The station is fuelled on 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 of 53 MW. The gas turbine was completed in 1995, 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 180 MW (4x30 MW and 1x60 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 operated by NRG as an intermediate plant, shutting down over weekends. 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 and operated as a peaking plant to provide support to the system during extreme weather and plant outages. Yabulu has a capacity of 159 MW. The station is owned and operated by Transfield. Yabulu has an annual sent out efficiency of ~31% (HHV).

Mt Stuart power station (1998)

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 AES Mt Stuart. Mt Stuart has an annual sent out efficiency of ~37% (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 282 MW (2x141 MW generating units) 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]

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. Callide A has an annual sent out thermal efficiency of ~27% (HHV).

Callide B, commissioned in 1998/99, has a capacity of 700 MW (2x350 MW generating units). Callide B has an annual sent out thermal efficiency of ~36% (HHV).

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

Swanbank power station, near Ipswich in southeast Queensland, consists of two coal-fired installations (Swanbank A & B) and two gas turbines (Swanbank C & D). 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). Swanbank A has an annual sent out thermal efficiency of ~28% (HHV).

Swanbank B is subcritical pf fired, was constructed in the 1970's and has a capacity of 500 MW (4x125 MW generating units). Swanbank B has an annual sent out thermal efficiency of ~33% (HHV). Both Swanbank A and B provide vital intermediate and peaking power to the Queensland market.

Swanbank C gas turbine is a 26 MW diesel-fired unit located adjacent to Swanbank's coal-fired units and Swanbank D gas turbine is a 37 MW emergency stand by unit running on diesel. Swanbank C & D have annual sent out thermal efficiencies of ~30%.

In August 2002, Swanbank's total capacity increased by 385 MW with the commissioning of Swanbank E, a combined cycle gas turbine fuelled by coal bed methane.

Callide Power Plant (2001)

Callide Power Plant is a supercritical pf fired power station located close to the original Callide power station near Ipswich in Queensland. Callide Power Plant has a capacity of 840 MW (2x420 MW generating units). At the end of June 2001, this $800 million joint venture between InterGen and CS Energy was 95% complete with the first of two 420 MW generators officially opened on the 4th July 2001. Callide Power Plant achieves an annual average sent out thermal efficiency of ~39% (HHV) – one of the best in Australia.

Middle Ridge power station (1970)

Middle Ridge is an oil fired open cycle gas turbine located near Toowoomba, 100 km west of Brisbane. Middle Ridge has a capacity of 56 MW and operates as a peaking station.

1.3.3 Stanwell Corporation[7]

Stanwell power station (1993/96)

Stanwell is a subcritical pf fired power station located on 22 km west of Rockhampton. Stanwell has a capacity of 1400 MW (4×350 MW generating units) and operates as a base load station. Coal for the power station is sourced via rail from Curragh coal mine, approximately 200 km west of the power station. 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 36% (HHV).

Mackay power station (1977)

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 power station (1984/86, 1983)

Tarong is a subcritical pf fired power station located at Nanango, 180 km west of Brisbane, and is one of Queensland's largest power stations. With a total generating capacity of 1400 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 to complete. Coal is supplied via conveyor from Meandu coal mine. Cooling water for the natural draft evaporative cooling towers is via pipeline from Boondoomba or Wivenhoe Dams. Tarong achieves an annual sent out thermal efficiency of ~34% (HHV).

Wivenhoe power station (1984)

Wivenhoe power station is a pumped storage hydroelectric plant, located on the eastern side of Wivenhoe Dam, about 90 kilometres north-west of Brisbane. Wivenhoe has a capacity of 500 MW (2x250 MW generating units), used for peaking loads.

1.3.5 Origin Energy

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).

1.4 Future generating capacity[1]

In 2000/01 the capacity factor of the Queensland grid was 55.0% (ie the installed capacity was operating at an average of 55.0% of full load over the entire year). For comparison, the capacity factors for NSW and Victoria were 58.1% and 68.7%, respectively.

The peak load for the Queensland grid in 2000/01 was 11,547 MW on the 24th January 2001.

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.

The proposed CCGT power station fuelled by syngas from underground (ie in-situ) coal gasification has not been included (despite on-going interest in this technology option) as the proposal is still unclear both in configuration and location.

Table 3 Proposed power stations in Queensland

Plant	Developer	Type	Size (MW)	Fuel Type	Proposed commission year
Tarong North	Tarong Energy	Supercritical pf	450	Coal	2003
Swanbank E[1]	CS Energy	CCGT	380	NG	2002
Townsville	Stanwell Corp	CCGT	766	NG	2003
West Surat	MIM/Entergy	Steam	700	Coal	N/a
Wambo (Kogan)	ERM Power /AIDC	GT	450	NG	N/a
Surat Coal Field	Surat Dawson Development	Steam	470	Coal	N/a
Peak Downs	BHP	Steam	230	Coal	N/a
Kogan Creek	AQC & CEPA	Steam	600/850	Coal	N/a

1. Power station is operational, however did not contribute to the Queensland electricity grid in the timeframe covered in the present study.

2 LCA METHODOLOGY

The study was based on a cradle-to-end user 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). Contribution from pumped storage was also omitted, as this is a net consumer of electricity (due to losses); however, there are also benefits from peaking and standby – these factors will be considered in a future study.

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 2001.

2.2 System boundary

This includes 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.

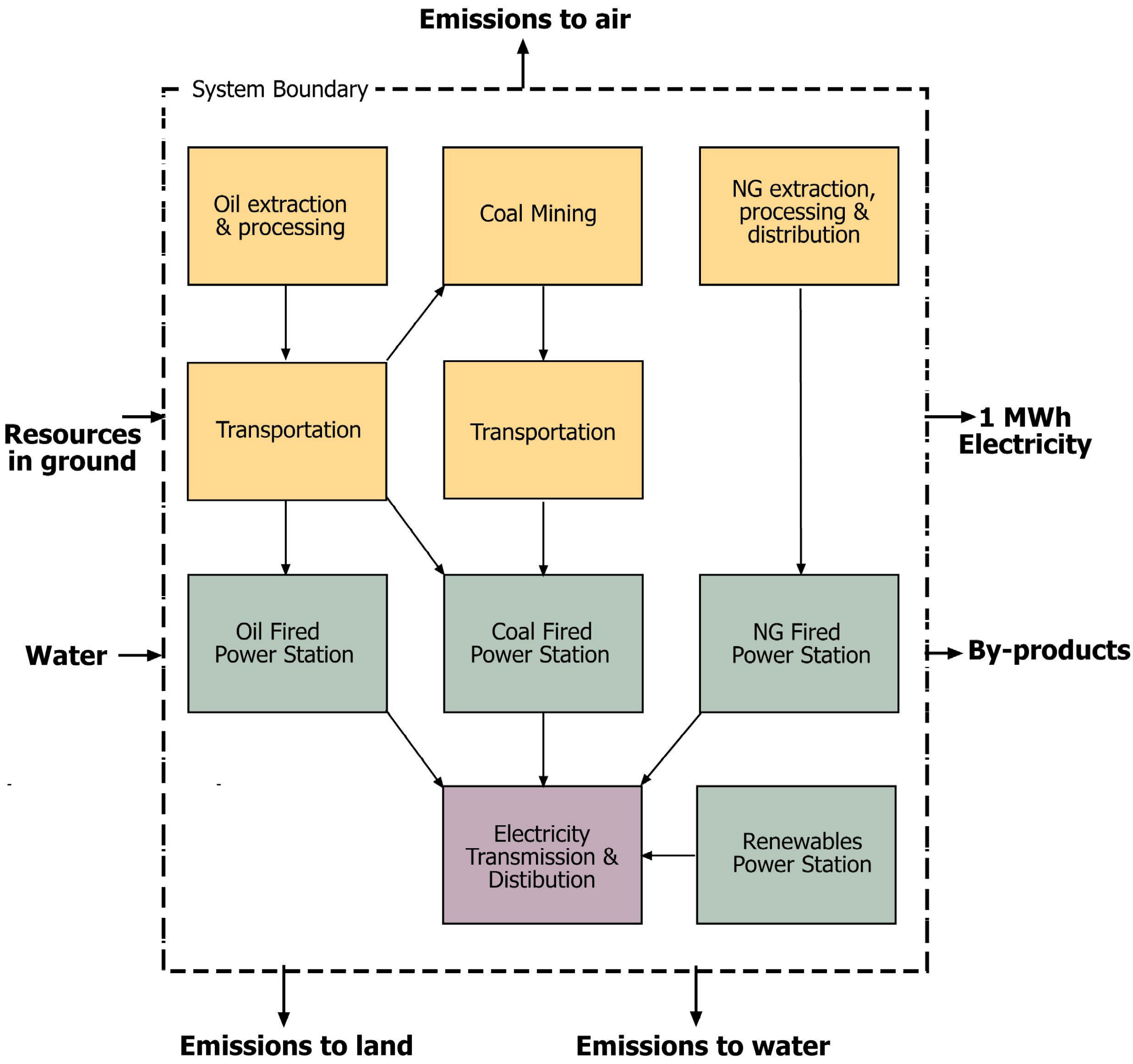

Figure 1 LCA system boundary

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)[9], company annual and environment reports[10,11,12], the National Pollutant Inventory[13], and others[14,15,16].

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	34.3	918	4.14	2.63	0.61	2.34
Gladstone	35.0	932	4.35	1.91	0.07	0.02
Stanwell	36.4	882	3.19	3.80	0.15	1.72
Callide A&B[c]	34.4	985	3.85	1.81	0.33	2.07
Swanbank A&B	31.0	962	2.91	3.96	0.11	2.96
Collinsville	26.3	1217	3.41	4.57	0.02	1.64
Callide Power Plant[c]	39.1	868	2.97	2.46	0.13	1.50

a) HHV, sent out basis
b) Calculated from fuel composition, allowing for 99% of carbon in fuel converted to CO_2
c) Chris Spero of CS Energy has indicated that the SO_x values for these stations may be incorrect, and we await further notification

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[9]).

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[9,17,18], US EPA and the Australian National Pollutant Inventory[13].

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.

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 accounts for approximately 12%

in Queensland. However, the breakdown of ash utilisation is unclear. Fly ash can be added for several purposes (including, for example, concrete pumpability) which values 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.

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 – an issue for a future more detailed study.

2.2.2 Transmission and distribution

Losses of electricity in transmission are sourced from the Electricity Supply Association of Australia 1997 report[19] and distribution are sourced from the Electricity Supply Association of Australia 2002 report[1], and represent a weighted average loss from the entire grid. These losses are 5.3% for high voltage transmission and 5.5% for distribution.

Table 5 Comparison of transmission and distribution losses for different grids

Grid	Transmission losses (%)	Distribution losses (%)
NSW	2.7	5.5
Victoria	2.5	6.7
Queensland	5.3	5.5
WA[1]	-	8.1

1. WA distribution losses include transmission losses

2.2.3 Coal

Coal is the primary fuel used for power generation in Queensland. Approximately 18.3 Mt of coal was used in 2001, all from domestic supply. Table 6 gives the coal used at each of the major power stations, the total used and the mode and distance of transport for each coal source. Data was sourced mostly from the Queensland Coal Review 2000-2001[20].

Table 6 Coals used in major Queensland power stations[20]

Station	Coals used	Amount (Mt)	Mode of transport	Distance (km)
Callide A & B	Callide (Southern)	2.97	Conveyor	5
Callide C	Callide (Southern)	0.20	Conveyor	5
Collinsville	Collinsville	0.27	Conveyor	10
Gladstone	Callide (Boundary Hill)	4.39	Rail	315
	Curragh	0.39	Rail	315
Swanbank A & B	Ebeneezer	0.46	Road	22
	Jeebropilly	0.76	Road	55
	Wilkie Creek	0.19	Rail	195
Stanwell	Blackwater	2.00	Rail	200
	Curragh	1.41	Rail	200
Tarong	Jeebropilly	0.42	Road	160
	Meandu	4.89	Conveyor	20
	TOTAL	18.35		

The weighted average coal composition for each station is given in Table 7. Data for coal composition was sourced from the Queensland Coal Industry Review 2000-2001[20], The Australian Coal Yearbook 1996[21], and the Coal 1998[22].

Table 7 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)
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	21.2
Swanbank A & B	58.2	4.5	1.1	0.5	8.1	16.4	11.3	25.3
Stanwell	66.4	3.7	1.4	0.6	4.0	14.2	9.7	27.1
Tarong	49.6	3.3	0.9	0.3	7.5	24.6	13.8	20.5

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[18].

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 Queensland natural gas) 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 Australian Coal Association, Canberra, and will require collaboration with the Australian gas industry.

However, as gas accounts for <1% 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 pipeline composition of Queensland natural gas (as used in the analysis) is given in Table 8. Natural gas pipeline specifications are sourced from the National Greenhouse Gas Inventory (NGGIC) and Australian Gas Association.

Table 8 Average composition of NG in Queensland pipeline [9,18]

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 9. Data was sourced from a range of company reports[10-12]. For the primary power stations, where specific chemical consumption data is not available, estimates based on other stations were used.

Table 9 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 the Cockle Creek Lead/Zinc smelter

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[17].

2.3 LCA considerations

There are a number of factors that may affect the LCA results:

- 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 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 representativeness of NPI data. Clearly values 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 10, together with the overall impacts on the GGE values.

Table 10 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[13]

The National Pollutant Inventory (NPI) 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 certain 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.

Currently, companies are required to report their emissions to air, land and water for 36 of the 90 substances listed on the NPI. Reporting on emissions of the longer list of 90 substances will commence when industry reports on 2001/02 emissions. Table 11 lists the 36 substances listed for the 1998-2001 period, which will be extended in the future. Table 11 also lists the associated reporting threshold, which is subject to 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 11 Substances listed on the NPI in the first three reporting years (1998-2001)[13]

Compound	Threshold category	Threshold (for reporting)
Acetone	1	10 t/yr
Arsenic & compounds	1	10 t/yr
	2b	2,000 t/yr,or 60,000 MWh,or rated at 20 MW
Benzene	1	10 t/yr
1,3-Butadiene (vinyl ethylene)	1	10 t/yr
Cadmium & compounds	1	10 t/yr
	2b	2,000 t/yr,or 60,000 MWh,or rated at 20 MW
Carbon monoxide	1	10 t/yr
	2a	400 t/yr, or1 t/hr
Chromium (VI) compounds	1	10 t/yr
	2b	2,000 tonnes per year,or 60,000 MWh,or rated at 20 MW
Cobalt & compounds	1	10 t/yr
Cyanide (inorganic) compounds	1	10 t/yr
1,2-Dibromoethane	1	10 t/yr

Compound	Threshold category	Threshold (for reporting)
Dichloromethane	1	10 t/yr
2-Ethoxyethanol	1	10 t/yr
2-Ethoxyethanol acetate	1	10 t/yr
Ethylene glycol (1,2-ethanediol)	1	10 t/yr
Fluoride compounds	1	10 t/yr
	2a	400 t/yr, or1 t/hr
Glutaraldehyde	1	10 t/yr
Lead & compounds	1	10 t/yr
	2b	2,000 t/yr,or 60,000 MWh,or rated at 20 MW
Mercury & compounds	1	10 t/yr
	2b	2,000 t/yr,or 60,000 MWh,or rated at 20 MW
Methanol	1	10 t/yr
Methyl ethyl ketone	1	10 t/yr
Methyl isobutyl ketone	1	10 t/yr
Methyl methacrylate	1	10 t/yr
Nickel carbonyl	1	10 t/yr
	2b	2,000 t/yr,or 60,000 MWh,or rated at 20 MW
Nickel subsulfide	1	10 t/yr
	2b	2,000 t/yr,or 60,000 MWh,or rated at 20 MW
Oxides of Nitrogen	2a	400 t/yr, or1 t/hr
Particulate Matter 10.0 µm (PM10)	2a	400 t/yr, or1 t/hr
Polycyclic aromatic hydrocarbons	2a	400 t/yr, or1 t/hr
Sulphur dioxide	1	10 t/yr
	2a	400 t/yr, or1 t/hr
Sulphuric acid	1	10 t/yr
Tetrachloroethylene	1	10 t/yr
Toluene (methylbenzene)	1	10 t/yr
Toluene-2,4- diisocyanate	1	10 t/yr
Total nitrogen (see notes above)	3	15 t/yr
Total phosphorus	3	3 t/yr
Trichloroethylene	1	10 t/yr
Xylenes (individual or mixed isomers)	1	10 t/yr

3 RESULTS

3.1 Energy and raw material flows

The resources consumed per MWh of power generated from the Queensland transmission grid are given in Table 12. It should be noted that the resources consumed represent the 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 12 Resource consumption per MWh of electricity from the Queensland transmission grid

Resource	Amount	Unit	Comment
Coal	0.5	t	Coal fired boiler fuel
Crude oil	0.095	GJ	For coal-fired boiler start-up, gas turbine peaking stations and transport fuel
Limestone	0.0001	t	Lime production for pH adjustment of power station cooling water
NG	0.076	GJ	Gas fired peaking stations and ammonia/ammonium nitrate production
Fresh water	1.74	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 (501 kg) and fresh water (1,740 kg). Chemical feedstocks, natural gas and petroleum based fuels and biomass are consumed at comparatively low rates.

Although not an actual resource, it should also be noted that hydro and other renewables contribute 1.9 kWh per MWh of electricity supplied by the electricity grid.

3.2 Impact assessment values

A summary of the results for the production of 1 MWh of electricity is shown in Table 13.

Table 13 Impact assessment values for 1 MWh of Queensland grid electricity (no interstate purchases)

Parameter	Transmission grid	Distribution grid	Comment
Inputs			
Resource energy (GJ)	11.41	12.08	97.8% coal, 0.84% crude oil, 0.67% NG
Fresh water (m^3)	1.74	1.84	Primarily for evaporative cooling
Outputs			
GGE (kg CO_2-e)	1028	1088	98% from power stations, 1.8% from coal mining
NOx (kg)	4.17	4.41	99% from fossil fuel power generation
SOx (kg)	2.96	3.13	99.8% from power generation
Particulates (kg)	0.77	0.81	61.5% from open cut coal mining, 38.5% from power generation
Solid waste (kg)	87.8	92.9	99% from power generation

The difference between 1 MWh of electricity from the transmission and distribution grids is are losses of 5.5% (average) in the distribution system.

To summarise:

- The resource energy consumption for the Queensland transmission grid is dominated by coal (97.8%), with only small contributions from natural gas, and oil.
- Greenhouse gas emissions are dominated by emissions from coal fired power stations (94%), followed by coal mining (5.1%).
- The majority of NO_x, SO_x and solid waste emissions are from coal fired power stations. For particulate emissions, open cut coal mining contributes a substantial proportion of the overall amount.
- Fresh water is consumed primarily by the inland coal fired power stations for condenser cooling. For the Queensland transmission grid, every MWh of electricity generated consumes, on average, 1.74 m^3.

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 14 shows the projected emissions from the Queensland grid, with comparison to the State total.

Table 14 Projected emissions from Queensland power generation compared to State total[13,25]

Parameter	Transmission grid 2000-01 (per MWh)	Distribution grid 2000-01 (per MWh)	Total from QLD grid 2000-01 (per annum)	Total QLD - all sources (per annum)	% of State
Resource energy	11.4 GJ	12.08 GJ	435.1 PJ	1,0401 PJ	41.8
Fresh water	1.74 m^3	1.84 m^3	66.2 GL	3,2422 GL	2.0
GGE	1028 kg CO_2-e	1088 kg CO_2-e	39.2 Mt	1121 Mt	35.0
NO_x	4.14 kg	4.41 kg	159 kt	290.03 kt	54.8
SO_x	2.96 kg	3.13 kg	113 kt	470.03 kt	24.0
Particulates	0.77 kg	0.81 kg	29.3 kt	152.73 kt	19.1

1. Projected from 1998 data (National Greenhouse Gas Inventory, Queensland State of the Environment 1999)
2. Annual human water consumption (Queensland State of the Environment 1999). Approximately 80% of water withdrawn from storage is used for agriculture.
3. 2000-01 data (National Pollutant Inventory website)

The comparison shows that a significant proportion of all 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.

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

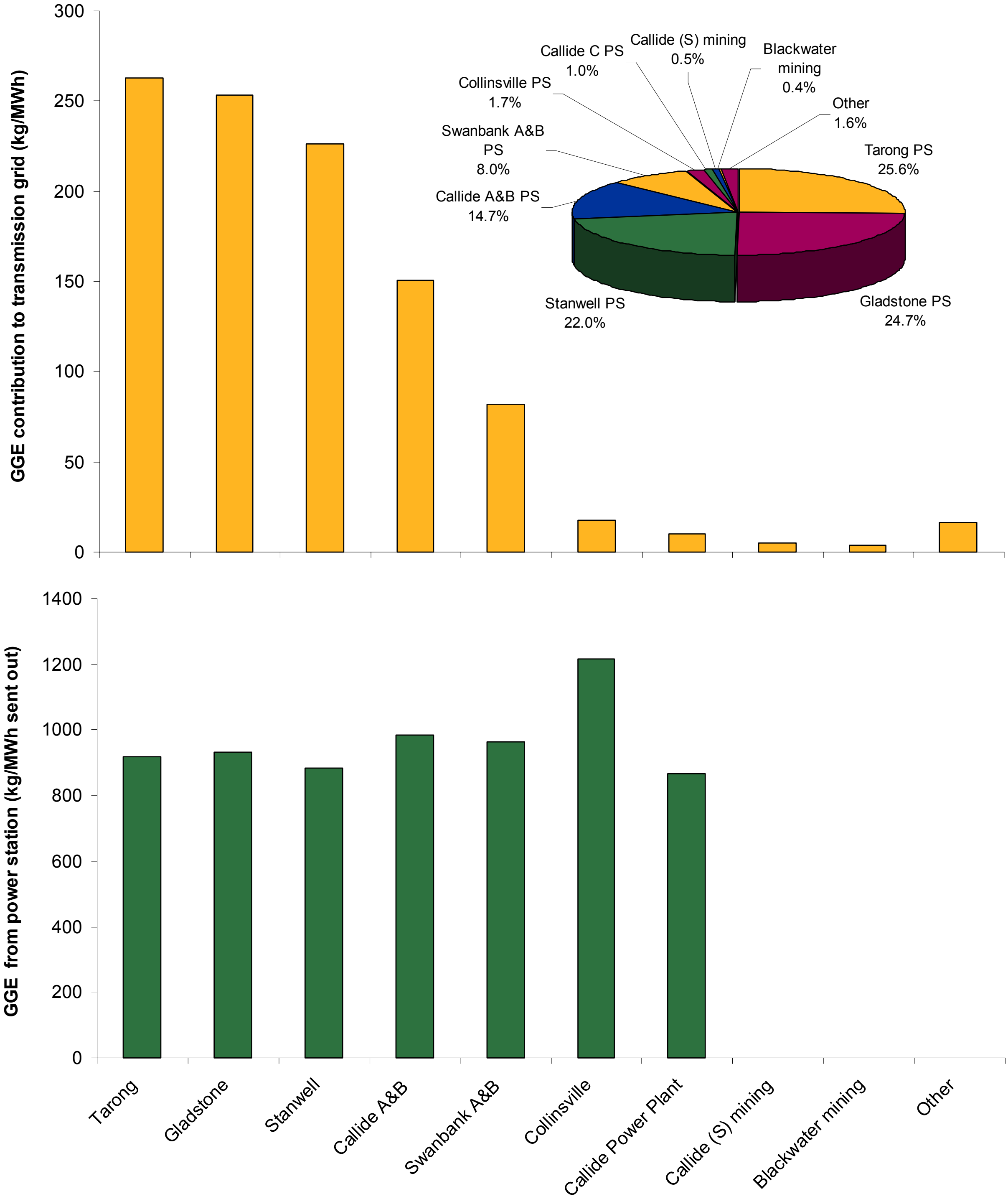

Figure 2 Breakdown of GGE per MWh of electricity from the Queensland transmission grid

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

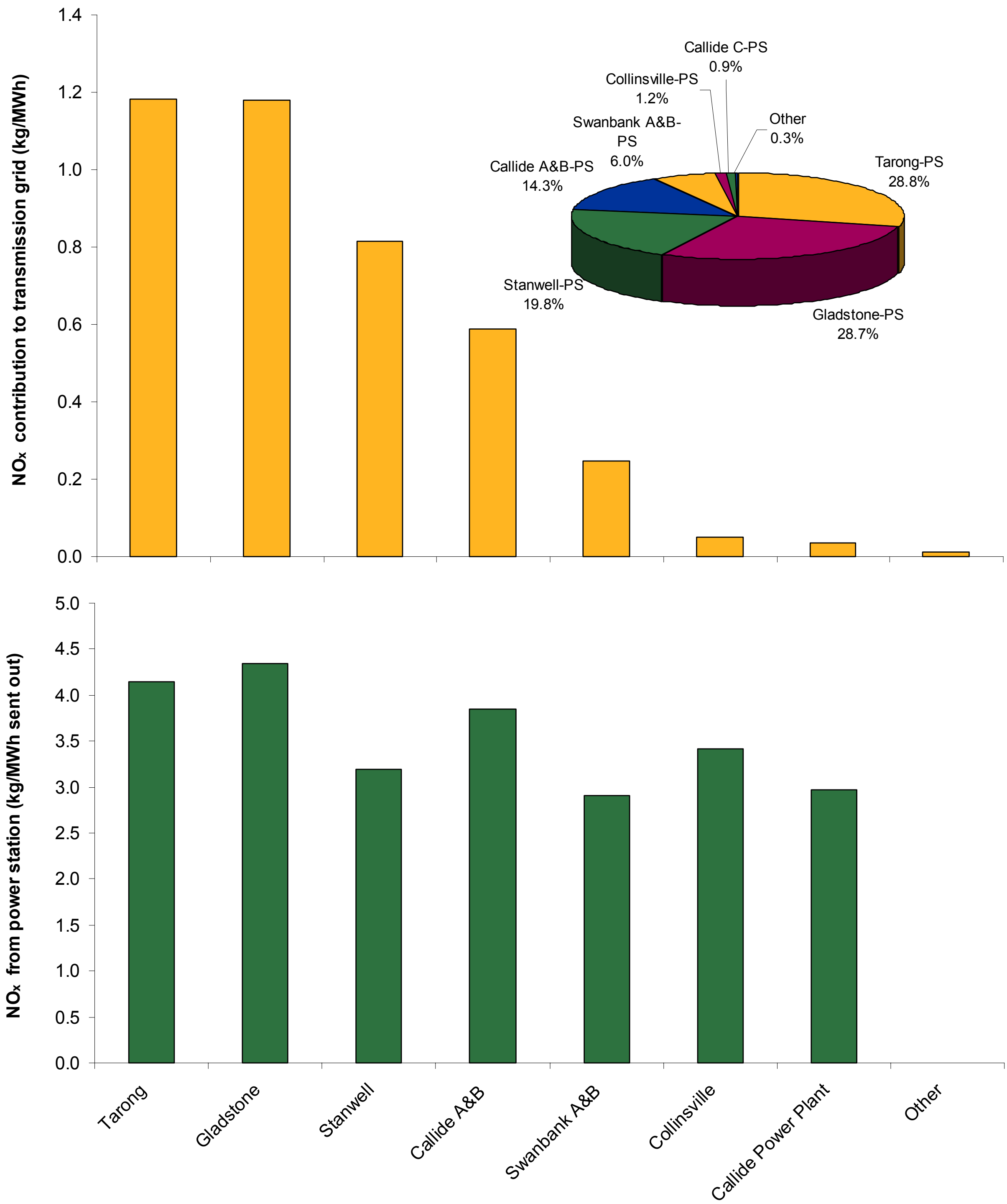

Figure 3 Breakdown of NO_x per MWh of electricity from the Queensland transmission grid

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

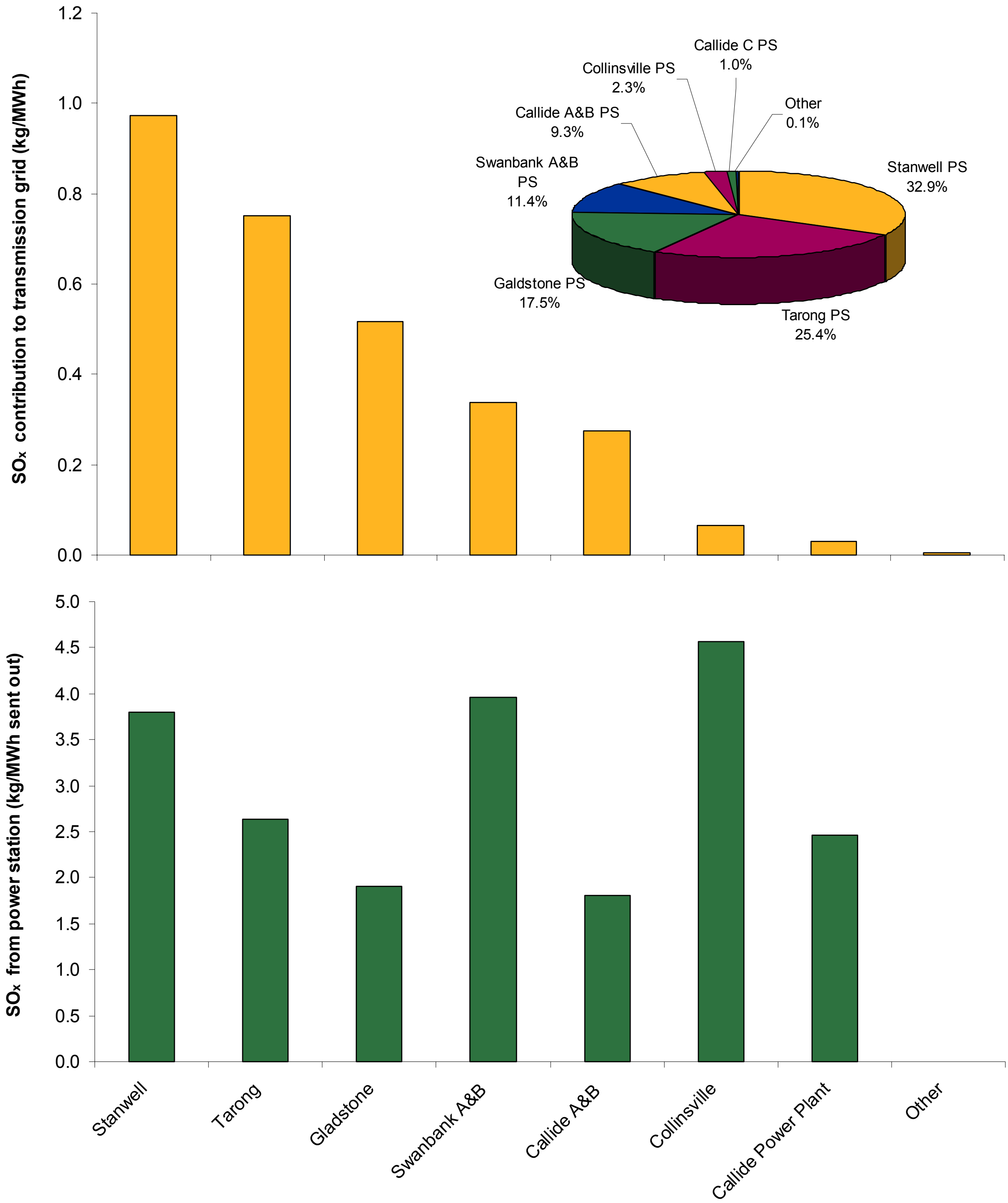

Figure 4 Breakdown of SO_x per MWh of electricity from the Queensland transmission grid

For particulates (Figure 5), six of the top ten emitters are open cut coal mines. Large coal fired power stations, especially those with electrostatic precipitators (Stanwell, Callide A&B), are significant contributors to particulate emissions per MWh of electricity from the Queensland transmission grid.

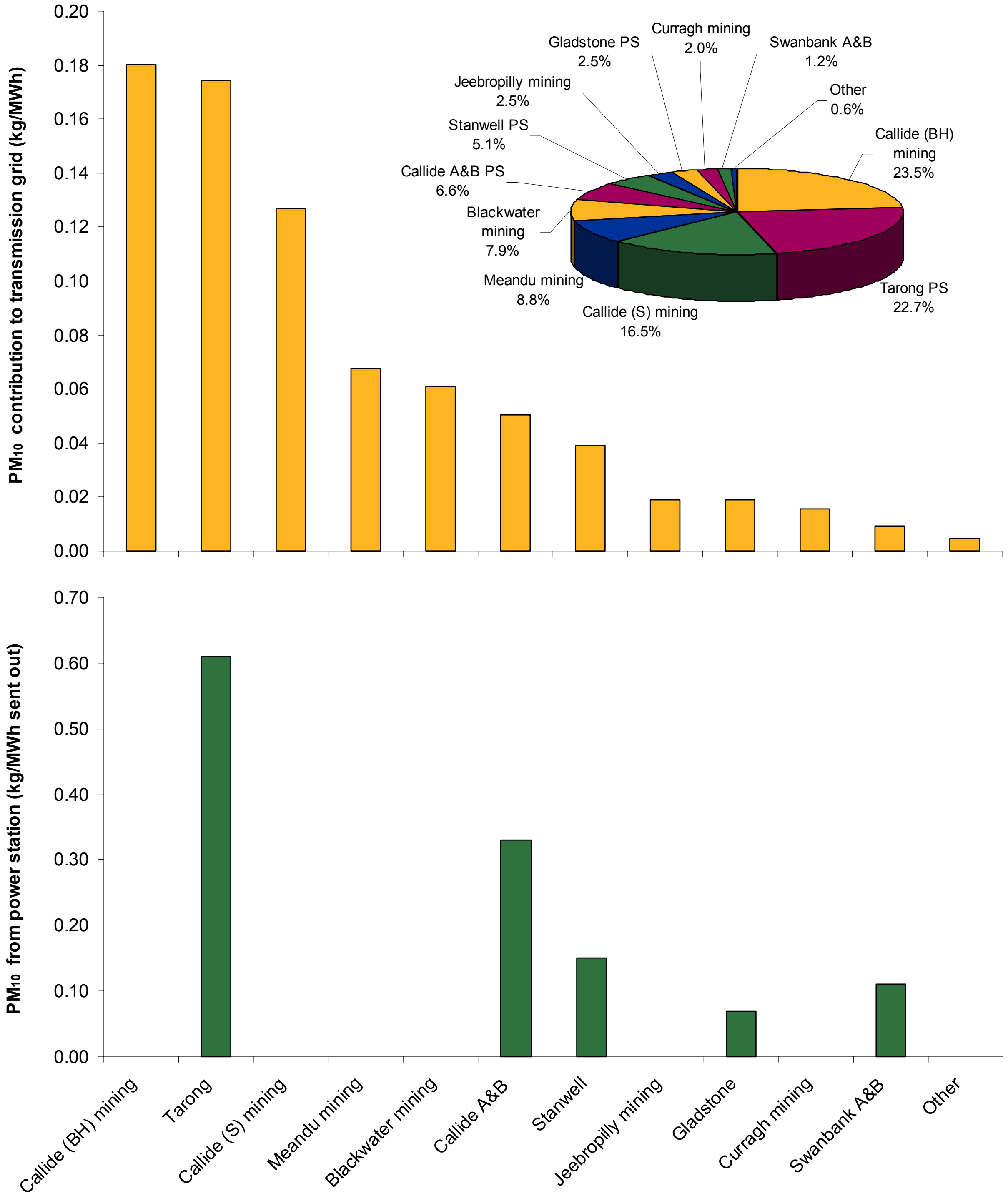

Figure 5 Breakdown of particulate emissions per MWh of electricity from the Queensland transmission grid

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.

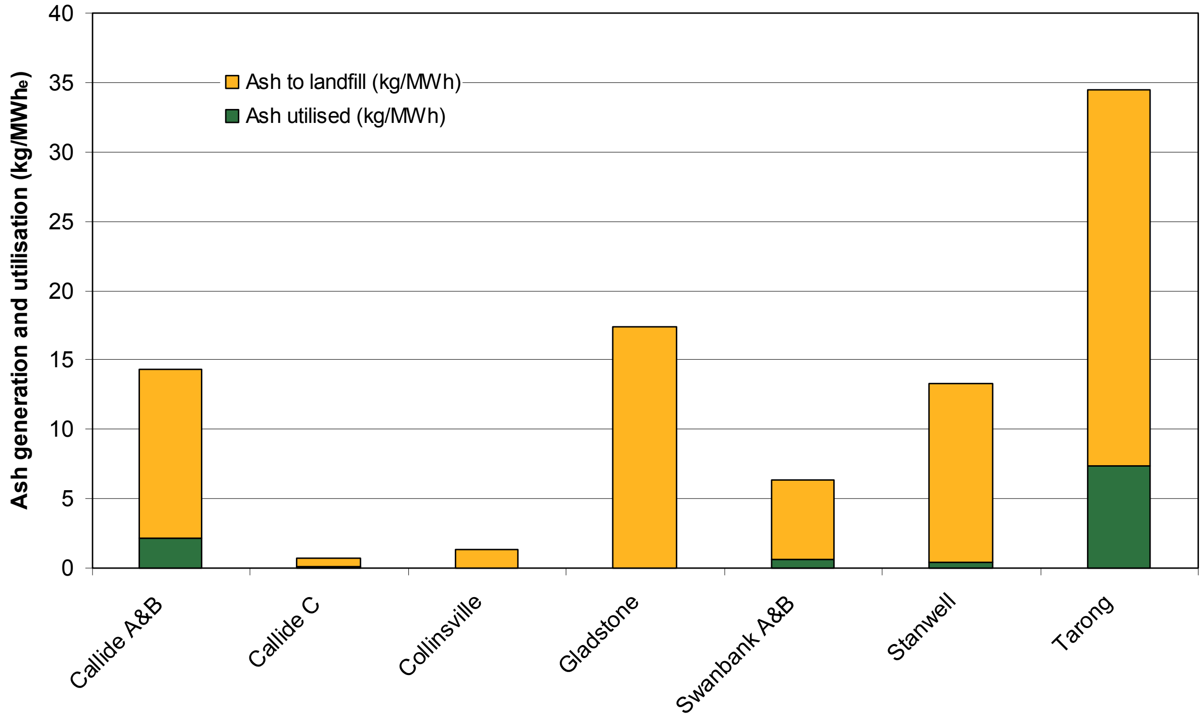

Figure 6 Breakdown of ash generation and utilisation per MWh of electricity from the Queensland transmission grid

The rate of utilisation of coal ash (fly and bottom ash) is on average approximately 12.1% (preliminary data). This is equal to a utilisation rate of approximately 10.6 kg/MWh or an annual use of 405,000 tonnes of ash from over 3.3 million tonnes of ash produced.

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 is approximately 1.1 Mt, and sales have been increasing (Ash Development Association of Australia, 2002)[26].

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 15, Table 16 and Table 17, reporting emissions to air, water and land, respectively. The results are given on a per MWh basis and on a tonnes per annum basis.

Table 15 NPI emissions to air per MWh of electricity from the Queensland transmission grid

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
1,3-butadiene (vinyl ethylene)	9.3×10^{-11}	0.004	Oil refining
Ammonia (total)	1.6×10^{-10}	0.006	Oil refining
Antimony & compounds	5.1×10^{-11}	0.002	1 coal mine
Arsenic & compounds	1.9×10^{-08}	0.7	7 coal mines, 8 power stations, oil refining
Benzene	8.8×10^{-08}	3.4	2 coal mines, 2 power stations, oil refining
Beryllium & compounds	9.1×10^{-11}	0.003	1 coal mine
Boron & compounds	4.4×10^{-09}	0.2	1 coal mine
Cadmium & compounds	2.3×10^{-09}	0.09	7 coal mines, 7 power stations, oil refining
Carbon monoxide	1.2×10^{-04}	4,641	7 coal mines, 11 power stations
Chromium (VI) compounds	7.5×10^{-08}	2.9	5 coal mines, 7 power stations, oil refining
Cobalt & compounds	2.4×10^{-08}	0.9	6 coal mines, 4 power stations, oil refining
Copper & compounds	1.5×10^{-09}	0.06	1 coal mine
Cyclohexane	4.0×10^{-10}	0.02	Oil refining
Ethylbenzene	3.7×10^{-11}	0.001	1 coal mine, oil refining
Fluorides	3.8×10^{-05}	1,430	7 coal mines, 8 power stations, oil refining
Formaldehyde (methyl aldehyde)	6.0×10^{-10}	0.02	Oil refining
Lead & compounds	6.1×10^{-08}	2.3	7 coal mines, 8 power stations, oil refining
Manganese & compounds	3.3×10^{-08}	1.3	1 coal mine
Mercury & compounds	1.9×10^{-08}	0.7	6 coal mines, 7 power stations, oil refining
Methanol	2.0×10^{-12}	<0.0001	Oil refining
Methyl ethyl ketone	1.5×10^{-08}	0.6	Oil refining
Nickel & compounds	2.2×10^{-09}	0.09	1 coal mine, oil refining
Oxides of nitrogen	4.1×10^{-03}	158,000	7 coal mines, 11 power stations
Particulate matter 10.0 mm	7.7×10^{-04}	29,230	7 coal mines, 11 power stations
Phosphorus (total)	2.7×10^{-11}	0.001	Oil refining
Polycyclic aromatic hydrocarbons	7.9×10^{-09}	0.3	4 coal mines, 9 power stations
Selenium & compounds	1.9×10^{-11}	0.001	1 coal mines
Sulfur dioxide	3.0×10^{-03}	112,600	7 coal mines, 10 power stations
Toluene (methylbenzene)	7.9×10^{-08}	3.0	2 coal mines, 4 power stations oil refining
Total nitrogen	4.4×10^{-09}	0.2	Oil refining

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
Total volatile organic compounds	3.1×10^{-06}	117	1 coal mine, 3 power stations
Xylenes (individual or mixed isomers)	5.3×10^{-08}	2.0	5 coal mines, 7 power stations, oil refining
Zinc & compounds	6.4×10^{-09}	0.2	1 coal mine, oil refining

Table 16 NPI emissions to water per MWh of electricity from the Queensland transmission grid

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
Arsenic & compounds	1.9×10^{-08}	0.4	2 coal mines, 5 power stations
Cadmium & compounds	3.8×10^{-10}	0.01	2 coal mines, 4 power stations
Chromium (VI) compounds	1.4×10^{-09}	0.05	3 coal mines, 1 power station
Cobalt & compounds	8.0×10^{-12}	0.0005	2 coal mines, 2 power stations
Fluorides	2.7×10^{-07}	10.2	3 coal mines, 4 power stations
Lead & compounds	1.0×10^{-09}	0.04	3 coal mines, 2 power stations
Mercury & compounds	5.3×10^{-11}	0.002	3 coal mines, 2 power stations
Sulfuric acid	2.6×10^{-08}	1.0	1 sulfuric acid plant

Table 17 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	2.0×10^{-12}	0.00008	2 coal mines
Benzene	1.1×10^{-10}	0.004	1 power station
Chromium (VI) compounds	2.4×10^{-11}	0.0009	2 coal mines
Cobalt & compounds	2.0×10^{-12}	0.00008	2 coal mines
Lead & compounds	2.1×10^{-11}	0.0008	2 coal mines
Polycyclic aromatic hydrocarbons	3.6×10^{-11}	0.0007	1 coal mine
Xylenes (individual or mixed isomers)	1.4×10^{-09}	0.05	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; of the order of micrograms (eg methanol to air, cobalt & compounds to water) up to kilograms (eg NO_x, SO_x). However, when these emissions are converted to a per annum basis, the quantities range from ~0.08 kg to 158,000 tonnes.

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 2001 were approximately 208,850 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 165,000 tonnes or approximately 79% of the total reported emissions. However, the NPI does not include emissions from many sources such as urban transportation. Also, many operations (such as some coal mines) may not exceed the reporting threshold for some emission types.

NPI data currently available does have inconsistencies when compared with other data sources (eg 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 12.1% 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 18).

Table 18 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	12.1% (current displacement assuming all ash to cement)	100% (maximum potential displacement)
Resource energy (GJ)	11.41	11.35	10.86
GGE (kg CO_2-e)	1,028	1,016	930
NO_x (kg)	4.17	4.15	4.00
SO_x (kg)	2.96	2.95	2.91

Table 18 shows that with current ash utilisation (assuming as cement extender) there is a greenhouse gas saving of 1.2%. If the ash utilisation was increased to 100% there would be a potential saving in greenhouse gas emissions of 9.5% overall or 8.5% 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.27

4 COMPARISON TO OTHER STUDIES

The Australian Greenhouse Office, under the Greenhouse Challenge programme, has published a range of full fuel cycle greenhouse gas emission values for Australian States and Territories[28] and values for Queensland are shown in Table 19.

Table 19 Comparison of greenhouse gas emissions from the Queensland electricity grid (comparisons for transmission and distribution)

Parameter	Present study	Greenhouse Challenge – Factors and Methods Workbook[27]
Transmission grid	1,028	975
Distribution grid	1,088	1,040

Table 19 shows that the results from the Greenhouse Challenge compare reasonably (within 5%) with those for the present study, though they differ by a larger percentage than found for similar studies for New South Wales and Victoria.

5 REFERENCES

1 Electricity Supply Association of Australia, Electricity Australia 2002

2 Electricity Supply Association of Australia, ESAA Statistics for the NEM 1999-2000

3 Electricity Supply Association of Australia, ESAA Statistics for the NEM 2000-2001

4 Enertrade internet site (http://www.enertrade.com.au/)

5 CS Energy internet site (http://www.csenergy.com.au/)

6 Swanbank power station information (http://www.home.gil.com.au/~swanbnk2)

7 Stanwell Corporation internet site (http://www.stanwell.com.au/)

8 Tarong Energy internet site (http://www.tarong.com.au/)

9 Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Fuel Combustion Activities (Stationary Sources), National Greenhouse Gas Inventory Committee, Workbook 1.1, Canberra, 1998.

10 Enertrade 2000-01 Annual Report

11 Stanwell 2001 Annual Report

12 Tarong Energy 2001 Annual Report

13 National Pollutant Inventory. Environment Australia (http://www.npi.gov.au)

14 Bayswater Power Station – Technical Information and Vital Statistics on Pacific Power's Leading Environmentally Managed Electricity Producer, Pacific Power Public Affairs.

15 Bayswater Power Station Environmental Impact Statement, June 1979 [Extract], Pacific Power, 1979.

16 McLennan Magasanik Associates Pty Ltd, "Projections of Price of Renewable Energy Certificates to Meet the 2% Renewable Energy Target", November 1999

17 Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Transport (Mobile Sources), National Greenhouse Gas Inventory Committee, Workbook 3.1, Canberra, 1998.

18 Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Fugitive Fuel Emissions (Fuel Production, Transmission, Storage and Distribution), National Greenhouse Gas Inventory Committee, Workbook 2.1, Canberra, 1998.

19 Electricity Supply Association of Australia, Electricity Australia 1997

20 NSW Department of Mineral Resources, "2002 Queensland Coal Industry Profile", February 2002

21 Australian Coal Yearbook – Tenth Edition, Volume 1, Australia's Mining Series, 1996

22 Coal 1998, Australian Coal Report, August 1998

23 Gas Statistics Australia 2001, Australian Gas Association, September 2001

24 Greenhouse Challenge Program, Greenhouse Challenge Facilitative Agreement, Australian Gas Association, November 1997 (from http://www.gas.asn.au/facilit.htm, last accessed: 21 June 2001).

25 Queensland State of the Environment 1999, Queensland Environmental Protection Authority, Brisbane, December 1999.

26 Ash Development Association of Australia website http://www.adaa.org.au/

27 Cement Industry Federation website (http:/www.cement.org.au)

28 Greenhouse Challenge, Factors and Methods Workbook Version 3 – December 2001, Australian Greenhouse Office