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**A LIFE CYCLE ASSESSMENT OF THE NEW SOUTH WALES
ELECTRICITY GRID**
(Year Ending 2003)

TECHNOLOGY ASSESSMENT REPORT 58

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October 2006



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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 New South Wales grid for CY2003, with a generation capacity of ~12,500MW. In this period, 61,294 GWh was sent out from the grid with a capacity factor of 56.5%. 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 New South Wales 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 the New South Wales electricity grid than reported in other studies (which have focused on greenhouse gas emissions alone). The study includes a range of indicators: 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 New South Wales grid. Comparisons with overall New South Wales values (from all major combustion, agricultural, waste and fugitive activities) are also included, to provide context.

Parameter	NSW grid 2000-01 (per annum)	NSWgrid CY2003 (per annum)	NSW - all sources (per annum)	% of State
Resource energy	654.2 PJ	632.9 PJ	1,533 PJ	41.3
Fresh water	67.5 GL	84.2 GL	9,425 GL	0.9
GGE	59.3 Mt CO ₂ -e	57.4 Mt CO ₂ -e	151 Mt	38.0
NO _x	178 kt	143 kt	305 kt	46.9
SO _x	250 kt	257 kt	300 kt	85.7
Particulates	11.7 kt	9.1 kt	73 kt	12.5

The table below shows the average inputs and outputs related to 1 MWh of power generation, on both a transmission and distribution grid basis.

Parameter	2001		CY2003		Difference ^a (%)
	Transmission grid	Distribution grid	Transmission grid	Distribution grid	
Inputs					
Resource energy (GJ)	10.75	11.38	10.67	11.30	- 0.7%
Fresh water (m ³)	1.11	1.17	1.51	1.59	+ 36.0%
Outputs					
GGE (kg CO ₂ -e)	974	1031	967	1025	- 0.6%
NO _x (kg)	2.92	3.09	2.40	2.55	- 17.8%
SO _x (kg)	4.14	4.38	4.33	4.59	+ 4.6%
Particulates (kg)	0.19	0.20	0.15	0.16	-21.1 %
Solid waste (kg)	111	117	104	111	- 6.3%

^a Based on transmission grid

Key findings are:

- Overall system efficiency has improved since 2001, though marginally. This is shown by the decrease in resource energy consumption per MWh output. The reasons behind such a small differential were that no power stations were commissioned or decommissioned in the time between studies, and that the percentage of total output for each power station remained reasonably constant over the period.
- Water consumption was seen to increase quite substantially over the past three years on a MWh basis. This was due to Macquarie Generation reporting water consumption at a much higher level in this period for their Bayswater and Liddell power stations. As these two stations are responsible for around 40% of the entire grid, this had a significant effect on total water consumption.
- The grid accounts for significant amounts of emissions, particularly GGE, NO_x, SO_x and particulate matter.
 - There was very little change in the greenhouse gas intensity of the grid, with a decrease of only 0.6%. This small decrease was in line with the decrease in required energy resource per unit of output. It is expected that, if the NSW government is successful with its program to increase gas generated electricity, greenhouse gas intensity will decrease significantly.
 - NO_x emissions from power generation contribute around 47% of the state total for all sources, (c.f. 43% in 2001). There has, however, been a considerable decrease in NO_x emissions per MWh of output over this time. The 18% reduction (2.92kg/MWh to 2.4kg/MWh) in NO_x emission intensity has been the result of reductions in NO_x intensity from most of the major power stations contributing to the grid.

- Electricity generation made a smaller contribution to the state total for SO_x emissions as a percentage in 2003 than it did in 2001. However, the SO_x intensity of the grid increased by 4.6%. This is the result of the four major contributors to the grid, Bayswater, Liddell, Eraring and Mount Piper, reporting higher intensities in this period. It is also noteworthy that Appin Tower power station (utilising coal bed methane) had a SO_x intensity three times greater than for the next highest polluter in 2001. This was erroneous data resulting in a higher than actual value in the 2001 data. It is likely that the increase from 2001 to CY2003 is greater than the 4.6% reported.
- Particulate emissions for the NSW grid are evenly spread between coal mines and power stations, with 52.2% coming from power stations and 47.7% from coal mines. The fact that power stations hold the dominant share is a result of the use of electrostatic precipitators at Wallerawang and Vales Point power stations. Overall, the emission per MWh of generation has decreased, as well as the grid's share of the state total.
- Transmission and distribution losses for 2003 were unavailable. The present study used the 1997 value published by the ESAA of 2.7% for transmission loss. The current value for distribution loss was obtained from the ESAA and was 5.6% for 2003, (compared to 5.5% in 2001).

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

- Improved data is required (disaggregated) for the NSW natural gas system (wellhead CO₂ stripping, leakage). The present analysis has used estimates based on average Australian data, which is believed to have considerably lower GGE than the present NSW 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 2003.
- 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.

1 INTRODUCTION

The purpose of this Life Cycle Analysis is to determine the environmental impacts of power generation in New South Wales 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, with and without contributions from the Snowy Mountains Hydroelectric Authority (SMHEA). 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 are 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). New South Wales has the largest generating capacity of all states in Australia, with a total installed capacity of 12,997 MW (June 2003).

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	2,587	5.1
SMHEA	3,756	-	-	3,756	7.4
Total	44,852	3,751	2,087	50,690	100

1.2 NSW grid^[1,2,3]

In CY2003, a total of 61,300 GWh of electricity was exported to the transmission grid from NSW power stations, with around 8,250 GWh of imports from interstate.

Table 2 New South Wales electricity grid data (excludes purchases from interstate, the Snowy Mountains Hydroelectric Authority, and pumped storage)

Station	Operator	Type	Capacity (MW)	Comm. year	Fuel	GWh sent out (CY2003)	GWh sent out (%NSW)
Eraring	Eraring Energy	Pf boiler	2640	1982	Coal	13,859	22.6
Bayswater	Macquarie Generation	Pf boiler	2640	1984	Coal	15,955	26.0
Liddell	Macquarie Generation	Pf boiler	2000	1971	Coal	8,070	13.2
Vales Point B	Delta Electricity	Pf boiler	1320	1978	Coal	6,671	10.9
Mt Piper	Delta Electricity	Pf boiler	1320	1992	Coal	7,921	12.9
Wallerawang	Delta Electricity	Pf boiler	1000	1976	Coal	5,458	8.9
Munmorah	Delta Electricity	Pf boiler	600	1969	Coal	226	0.4
Redbank	National Power	CFBC boiler	150	2001	Coal	1,027	1.7
Smithfield	Sithe Energy	CCGT	177.5	1997	NG	938	1.5
Hunter Valley	Macquarie Generation	Gas turbine	50	1988	Oil	0.57	0.0
Broken Hill	Eraring Energy	Gas turbine	50	1989	Oil	0	0.0
Appin/Tower	Energy Development	Reciprocating engines	96	1997	CSM ¹	603	1.0
Hume	Eraring Energy	Hydro	58	1957	Oil	2	0.0
Warragamba	Eraring Energy	Hydro	50	1959	Hydro	90 ²	0.1
Burrendong	Power Facilities	Hydro	20	1996	Hydro	35	0.1
Copeton	Power Facilities	Hydro	20	1996	Hydro	70	0.1
Yarrowonga	Power Facilities	Hydro	9	1997	Hydro	16 ²	0.0
Burrinjuck	Eraring Energy	Hydro	28	1938/ 2002	Hydro	20	0.0
Keepit	Eraring Energy	Hydro	6	1938	Hydro	20	0.0
Glenbawn	Power Facilities	Hydro	5.8	1995	Hydro	16	0.0
Brown Mountain	Eraring Energy	Hydro	4	1938	Hydro	20	0.0
Nymboida	Country Energy	Hydro	9.8	1928	Hydro	25	0.0
Oakey	Country Energy	Hydro	5		Hydro	12	0.0
Blayney	Eraring Energy	Wind	10	2000	Wind	17 ²	0.0
Crookwell	Eraring Energy	Wind	5	1999	Wind	9	0.0
Total			12,514			61,294	99.8

1. Coal seam methane

2. Data estimated based on capacity and assumed capacity factor

Table 2 gives details of the principal stations and the other grid connected (embedded) facilities on the New South Wales grid.

Another significant factor is the distribution grid. The low voltage distribution grid is currently controlled by Energy Australia, Integral Energy, and Country Energy (formerly Advance Energy, Great Southern Energy and NorthPower, amalgamated July 2001). However, during the time period considered in this study, there existed another distribution

company, Australian Inland Energy and Water Infrastructure, which merged with Country Energy on 1st January 2005.

1.3 Primary NSW generators

The primary generators contributing to the grid are Macquarie Generation, Delta Electricity, Eraring Energy, National Power (US), Sthe Energies and SMHEA. The National Electricity Market (NEM) treats the SMHEA, which sells power generated to the NSW and Victorian grids, as a separate entity. There are also grid interconnections with Queensland and Victoria.

Transgrid and TransÉnergie operate the high voltage transmission grid.

The major facilities for each of the significant generators are described below.

1.3.1 Macquarie Generation^[4]

Macquarie generation owns and operates two of the three largest stations connected to the grid, Bayswater and Liddell as well as the Hunter Valley gas turbines. With a total capacity of 4,690 MW, Macquarie Generation sent out 24,015 GWh to the grid, a share of 39.2% of the total.

Bayswater power station (1984-85)

Bayswater is a subcritical pf fired power station located near Muswellbrook in the Hunter Valley, and is the equal largest power station in Australia (Eraring has the same capacity), consisting of 4×660 MW generators, or an overall capacity of 2,640 MW. Coal is supplied by conveyor from nearby open-cut mines. Condenser cooling is via four large natural draft cooling towers, with makeup water sourced from the Hunter River. Bayswater achieves an annual average sent out thermal efficiency of ~35.6% (HHV).

Liddell power station (1971-73)

Liddell is a subcritical pf fired power station located near Muswellbrook in the Hunter Valley, close to the Bayswater power station. It was the first power station in NSW to be located inland, away from the abundant supply of salt water cooling. Lake Liddell was constructed around the power station to provide cooling water, which is topped up from the Hunter River. Liddell power station consists of 4×500 MW (2,000 MW) generators, with coal supplied by conveyor from nearby open-cut mines. Liddell achieves an annual average sent out thermal efficiency of ~32.7% (HHV).

Hunter Valley gas turbines (1988)

Hunter Valley power station is an open cycle fuel oil fired gas turbine located near Liddell power station in the Hunter Valley. It has a capacity of 50 MW (2×25 MW) and operates as a peaking station. The station achieves an annual average sent out thermal efficiency of ~28% (HHV).

1.3.2 Delta Electricity^[5]

Delta electricity owns 4,240MW of capacity, shared between 4 major power stations, Vales Point, Mt Piper, Wallerawang and Munmorah. In 2003, Delta provided 33.1% of the state total, sending out a total of 20,276 GWh.

Mt Piper power station (1992-93)

Mt Piper is a subcritical pf fired power station located in the Central West region of New South Wales, approximately 25 km west of Lithgow. Mt Piper has a capacity of 1,320 MW (2×660 MW generating units). Coal from surrounding coal mines is burned in the power station boilers. Cooling water for use in the evaporative cooling towers is sourced from Lyle Dam on Cox's River via a 20 km pipeline. Mt Piper achieves an annual average sent out thermal efficiency of ~37.2% (HHV).

Wallerawang power station (1976, 1980)

Wallerawang is a subcritical pf fired power station located in the Central West region of New South Wales, approximately 15 km west of Lithgow. Wallerawang has a capacity of 1,000 MW (2×500 MW generating units). Coal is sourced primarily from the Angus Place mine via a private haul road. Cooling water for the evaporative cooling towers is sourced from two dams on Cox's River. Wallerawang achieves an annual average sent out thermal efficiency of ~33.2% (HHV).

Vales Point B power station (1978)

Vales Point is a subcritical pf fired power station located at the southern end of Lake Macquarie, about 35 km south of Newcastle. Built in the mid 1960's, it was the first station to be built at the site of its fuel source, with local mines supplying coal. Two additional units were installed in 1978-79, and the original four units were decommissioned in 1989. Vales Point now has a capacity of 1,320 MW (2×660 MW generating units). Coal is supplied from a range of sources, though mainly by conveyor from nearby underground mines. Condenser cooling water is drawn from, and discharged to, Lake Macquarie. Vales Point achieves an annual average sent out thermal efficiency of ~35.6% (HHV).

Munmorah power station (1969)

Munmorah is a subcritical pf fired power station located on the New South Wales Central Coast, about 110 km north of Sydney. Munmorah has a capacity of 600 MW (2×300 MW generating units). Coal is supplied via conveyors from local underground coal mines. Condenser cooling water is drawn from Lake Munmorah and discharged to Lake Budgewoi. Munmorah power station achieves an annual average sent out thermal efficiency of ~32% (HHV).

1.3.3 Eraring Energy^[6]

Eraring Energy owns Eraring power station as well as several renewable energy stations including 5 hydro plants, 1 pumped hydro plant and 2 wind farms. From a total capacity of 3,090MW, Eraring Energy produced 14,250 GWh of electricity, 23.2% of the state total.

Eraring power station (1982-84)

Eraring is a subcritical pf fired power station located on the western shores of Lake Macquarie, approximately 40 km from Newcastle, and is the equal largest power station in Australia with a capacity of 2,640 MW (4×660 MW generators). Coal for the power station is transported via conveyor from local mines, and via road or rail from other mines. Condenser cooling water is drawn from Lake Macquarie at Bonnells Bay and returned to the adjacent Myuna Bay. Eraring achieves an average sent out thermal efficiency of ~36.4%.

Shoalhaven power station (1977)

Shoalhaven hydroelectric power station is located near Nowra on the NSW South Coast. It is a pumped storage station used for peaking loads and has a capacity of 240 MW.

Broken Hill power station (1989)

Broken Hill power station is an open cycle fuel oil fired gas turbine located at Broken Hill in the far west of New South Wales. It has a capacity of 50 MW (2×25 MW) and operates as a peaking station. The station achieves an annual average sent out thermal efficiency of ~28% (HHV).

Hume power station (1957)

The Hume hydroelectric power station was retrofitted to the Hume Dam, which was constructed across the Murray River at Hume Weir in 1936. The 58 MW power station generates power from controlled water releases from the dam (only 20% annual capacity factor).

1.3.4 Sithe Energies^[7]

Sithe Energies is an American company which owns one plant in NSW. Its Smithfield plant produced 938GWh in 2003, equivalent to 1.5% of the state total.

Smithfield power station (1997)

Smithfield combined cycle gas turbine power station is located in Western Sydney and comprises 3×57 MW gas turbines with three heat recovery steam boilers and a 65 MW steam turbine. The steam produced is both sold to adjacent industrial plants and used in the steam turbine. Cooling is via cooling towers with water from Sydney Water. Smithfield achieves an annual average sent out thermal efficiency of ~42.4% (HHV – assumes that power generation is 42% efficient and does not include the heat (steam) supplied to adjacent industry). Since the conclusion of the period considered in this study, Sithe Energies was acquired by a Japanese company, Marubeni Corporation.

1.3.5 National Power

National Power owns the Redbank power station operating just south of Singleton. With a capacity of 150MW it provided 1,027GWh to the grid in 2003, 1.7% of the state total.

Redbank power station (2001)

Redbank power station consists of a sub-critical circulating fluidised bed boiler with a generation capacity of 150 MW. Redbank is located approximately 15 km south of Singleton in the Hunter Valley. The fluidised bed combustor is used to burn beneficiated dewatered tailings (BDT). BDT is sourced from tailings generated by the nearby Warkworth coal washery and transferred to the power plant via a 4 km conveyor^[8,9]. Condenser cooling is via cooling towers using water from the Hunter River. Annual average operating efficiency of Redbank is assumed to remain unchanged from the 2001 value of 32% (sent out, HHV). This was an estimate based on best available advice.

1.4 Future generating capacity^[1]

In 2002/03, (latest available data), the capacity factor of the New South Wales grid was 56.5% (*ie* the installed capacity was operating at an average of 56.5% of full load over the entire year).

Over the same period, the capacity factors for Queensland and Victoria were 53.1% and 65.8%, respectively.

The peak load for the New South Wales grid in 2002/03 was 12,331 MW on the 30th 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 New South Wales plants are listed in Table 3.

Table 3 Proposed power stations in New South Wales

Plant	Developer	Type	Size (MW)	Fuel Type
Bayswater (upgrade)	Macquarie Generation	Steam boiler	160	Black coal
Broadwater	Delta Electricity	Cogeneration	30	Biomass
Condong	Delta Electricity	Cogeneration	30	Biomass
Tomago stage I	Macquarie Generation	Gas turbine	260	NG
Tomago stage II	Macquarie Generation	Gas turbine	260	NG
Tomago stage III	Macquarie Generation	Steam turbine	270	NG

2 LCA METHODOLOGY

The study was based on a cradle-to-gate analysis for the generation, transmission and distribution of power in New South Wales. It excludes power station construction and non-grid generation (mostly small and remote facilities), or grid-connected facilities which do not result in net export of power (*eg* Bluescope Steel*, Port Kembla). Losses due to pumped storage are included in transmission losses.

The functional unit is 1 MWh of electricity supplied from the New South Wales grid (transmission and distribution) in the 12 months ending December 2003.

2.1 System boundary

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

Interstate purchases of electricity are not included in the study.

* Formerly BHP Steel

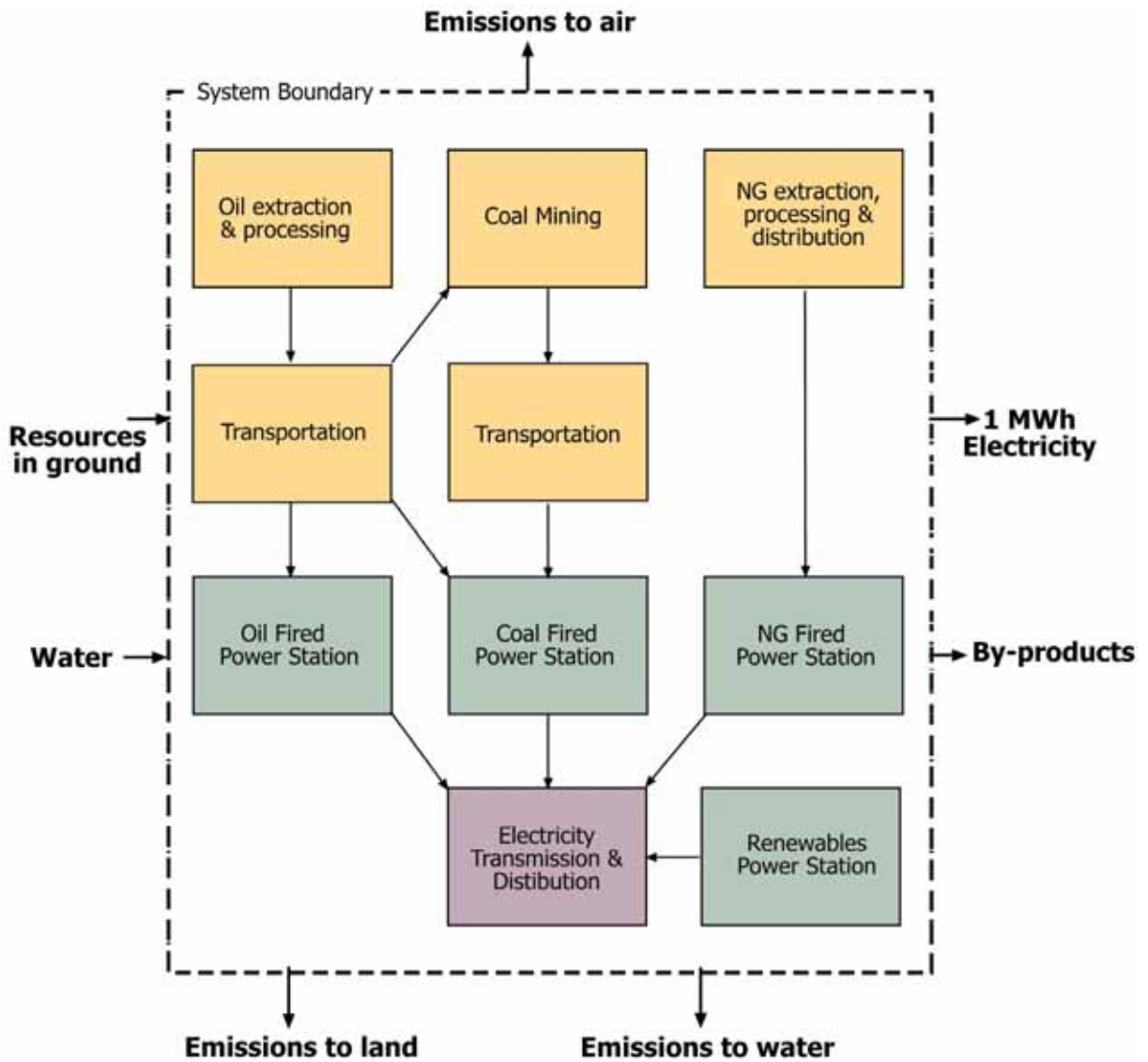


Figure 1 LCA system boundary

2.1.1 Power plant data

Data for the primary plants are summarised in Table 4, using information sourced from the Energy Supply Association of Australia, (formerly 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^[14], and others^[15,16,17].

Table 4 Efficiency and emissions data for the primary generators contributing to the New South Wales transmission grid – on a station basis. NPI values shaded^a

Station	Efficiency ^b (%)	CO ₂ ^c (kg/MWh)	NO _x (kg/MWh)	SO _x (kg/MWh)	PM ₁₀ (kg/MWh) ^d	Fresh water (m ³ /MWh)
Appin/Tower	32.1 ^e	569 ^f	2.73	0.003	-	Not reported
Bayswater	35.6	879	2.3	5.44	0.02	2.29
Eraring	36.4	870	2.27	3.24	0.07	0.1 ^g
Hunter Valley	28.0	940	17.1	Not reported	Not reported	0
Liddell	32.7	949	2.21	4.96	0.07	3.05
Mt Piper	37.2	843	2.9	4.29	0.02	1.55
Munmorah	32.0	984	2.21	2.92	0.09	0.3 ^g
Smithfield	42.4	431	0.21 ^h	0.003	0.014	Not reported
Redbank	32.0	978	0.56	2.04	0.12	2.08
Vales Point B	35.6	896	2.40	3.3	0.23	0.13 ^g
Wallerawang	33.2	893	2.02	4.2	0.17	1.81

- a) Note that the NPI data is in some cases weighted averaged values for FY2003 and FY2004 based on electricity generation
- b) HHV, sent out basis
- c) Calculated from fuel composition, allowing for 99% of carbon in fuel converted to CO₂.
- d) Considerable variability in data sources – refer to table below.
- e) Estimate
- f) Actual emissions from generation – overall this facility results in negative net emissions due to the avoidance of fugitive CH₄. This net saving is shown in the LCA results.
- g) Boiler make-up only, cooling water is drawn from nearby lakes
- h) Dry, low NO_x combustor

Table 5 is intended to show the variation in data between company reports and NPI data. It is important to note that the data used is derived from the NPI data values in all cases. Weighted averages based on generation have been used for data which was reported for financial years.

Table 5 Particulate emissions from primary generators, 20003-2004 ^a

Station	Flue gas particulate control	NPI 02-03 (t)	NPI 03-04 (t)	Company reports (t)	Data Used (t)	PM ₁₀ (kg/MWh)
Appin/Tower	nil	0.12	0.13	not reported	-	-
Bayswater	Fabric filters	380	386	314	380	0.02
Eraring	Fabric filters	CY data	CY data	not reported	980	0.07
Hunter Valley	nil	below threshold	below threshold	not reported	-	-
Liddell	Fabric filters	294	800	1240 ^b	530	0.07
Mt Piper	Fabric filters	CY data	CY data	128	190	0.02
Munmorah	Fabric filters	CY data	CY data	17	20	0.09
Smithfield	nil	below threshold	0	not reported	-	-
Redbank	Fabric filters	230	36	not reported	125	0.12
Vales Point B	ESP	CY data	CY data	1451	1530	0.23
Wallerawang	ESP	CY data	CY data	174	940	0.17

a) Note that data used is for the year ending December 2003, and the NPI data reported here has been adjusted for comparison with company reports which contain financial year values. Some weighted averages were employed to convert NPI data from FY to CY, the basis being electrical generation.

b) It is assumed that the Macquaire Generation Annual Report 2003 reported total particulate matter for Liddell Power Station (*ie* including those >10 µm), whereas NPI data for the same period reported only PM₁₀.

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 CO₂ 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^[10,18,19], 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 stations such as Eraring, Munmorah and Vales Point utilise saltwater cooling with large volumes of sea or lake 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. Liddell power station uses a dedicated lake (Lake Liddell) to provide cooling water, with heat dissipation directly from the lake via a combination of evaporation and convective effects. Nearly all make up water for Bayswater and Liddell is sourced from the Hunter River.

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 14% (870 kt) of the total coal ash generated in NSW in CY2003. Fly ash can be added for several purposes (including, for example, concrete pumpability). The effective replacement rate for Portland cement can be 1:1 (cement: fly ash replacement), and replacement can be up to 1:1.5 for other applications.

The breakdown of ash utilisation in NSW for FY2003 is shown for major coal-fired power stations as a percentage of total ash produced in Table 6.

Table 6 Ash utilisation as a percentage of ash production ^[11,12,20]

Operator	Power station	Percentage of Coal ash recycled (%)
Macquarie Generation	Bayswater & Liddell	65,715 tonnes ~5.3% ^a
Delta Electricity	Munmorah	0
	Wallerawang	0
	Mount Piper	17.0
	Vales point	13.5
Eraring Energy	Eraring	50.5

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

The case of Eraring power station is of particular interest, demonstrating the benefits of being located close to markets. Considering the cost of transporting recycled coal ash, Eraring is best able to exploit the opportunity to sell their ash due to its close proximity to Newcastle.

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 NSW grid.

2.1.2 Transmission and distribution

Losses of electricity in transmission were sourced from the Electricity Supply Association of Australia 1997 report, 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 (with SMHEA and interstate effects omitted). These losses are 2.7% for high voltage transmission, and 5.63% for distribution.

Table 7 Comparison of transmission and distribution losses for different grids (2003 data)

Grid	Transmission losses (%) ²	Distribution losses (%)
NSW	2.7	5.6
Victoria	2.5	6.0
Queensland	5.3	5.8
WA ¹	-	7.8

1 WA distribution losses include transmission losses

2 Transmission losses assumed to be the same as for 2000/2001

2.1.3 Coal

Coal is the primary fuel used for power generation in New South Wales. Approximately 25.8 Mt of coal was used in 2003, all from domestic supply. Table 8 gives the coal used at each of the major power stations, as well as the total used and the mode and distance of transport for each major coal source.

Table 8 Coals used in major New South Wales power stations¹

Station	Coals used	Amount (Mt)	Mode of transport	Distance (km)
Bayswater	Bayswater	7.23	Conveyor	12.0
	Drayton		Conveyor	8.0
	Narama		Road	9.0
	Ravensworth		Conveyor	8.5
Liddell	Drayton	4.16	Conveyor	8.0
	Ravensworth		Conveyor	8.5
Eraring	Cooranbong	5.63	Conveyor	1.5
	Newstan		Road	12.0
	Myuna		Conveyor	4.5
	Ulan		Rail	310
	Westside		Road	13.0
Mt Piper	Angus Place	3.10	Road	7.0
	Cullen Valley		Road	5.0
	Enhance Place		Road	5.0
	Invincible		Road	7.0
	Ivanhoe		Road	1.0
	Springvale		Conveyor	11.0
Wallerawang	Angus Place	2.27	Road	7.0
Vales Point B	Chain Valley	2.82	Road	1.0
	Munmorah		Conveyor	6.5
	Stratford		Rail	100
	Warkworth		Conveyor/Rail	3, 90
	Westside		Road	22.0
	Wyee		Conveyor	1.6
Munmorah	Munmorah	0.10	Conveyor	1.1
Redbank	Warkworth Tailings	0.53	Conveyor	3.4

1.) This table only shows major coal providers. Small amounts of coal may be sourced from other mines.

The weighted average coal composition for each station is given in Table 9. Data for coal composition were sourced from The Australian Coal Yearbook 1996^[21], and Coal 2004^[22].

Table 9 Weighted average composition of coals used at each of the major power stations (as received basis)

Station	C (%)	H (%)	N (%)	S (%)	O (%)	Ash (%)	TM (%)	SE (HHV) (GJ/t)
Bayswater	53.5	3.5	1.2	0.5	6.4	24.7	10.1	22.4
Liddell	49.7	3.3	1.1	0.5	6.3	30.4	8.8	20.9
Eraring	59.0	3.7	1.2	0.4	6.6	21.0	8.2	24.3
Mt Piper	59.3	3.7	1.4	0.5	6.1	21.2	8.0	24.7
Wallerawang	59.1	3.7	1.3	0.5	5.8	21.7	8.0	26.0
Vales Point	58.2	3.7	1.2	0.4	6.3	22.2	8.0	23.8
Munmorah	63.6	4.0	1.2	0.4	7.3	19.0	4.5	26.3
Redbank	51.8	3.3	1.2	0.3	5.4	8.0	30.0	21.6

2.1.4 Natural gas

Natural gas supply to the New South Wales 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^[19].

The CO₂ content of the raw natural gas (which is stripped to give < 2% CO₂, ie. 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 CO₂ contents (< 3% v/v, from available proprietary data). However, the raw CO₂ content of wells in the Cooper-Eromanga basin (largest supplier of NSW 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 generation. There are also issues regarding leakages in transportation which are yet to be quantified. These issues are 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 New South Wales generation, the overall effects on delivered electricity will be small. The main objective of a more accurate assessment would be to obtain a one-on-one comparison of generation technologies using different energy sources (eg. coal-fired versus gas-fired generation). For gas, wellhead stripping is likely to become more significant.

The pipeline composition of NSW natural gas (as used in the analysis) is given in Table 10. Natural gas pipeline specifications are sourced from the National Greenhouse Gas Inventory (NGGIC).

Table 10 Average composition of NG in NSW pipeline^[25]

Component	Vol. %
Methane (CH ₄)	89.9
Ethane (C ₂ H ₆)	7.2
Propane (C ₃ H ₈)	0.1
CO ₂	1.6
SE (MJ/Nm ³)	38.9

2.1.5 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 11. Data were sourced from a range of company reports^[11-13]. For the primary power stations, where specific chemical consumption data are not available, estimates based on other stations were used.

Table 11 Consumables used, manufacturing process and location

Consumable	Use	Location of manufacture
ANFO	Overburden blasting at open cut coal mines	Ammonium nitrate (produced from natural gas) at Incitec on Kooragang Island (Newcastle). Fuel oil produced at NSW oil refinery at Botany. ANFO is mixed at a batching plant near the mine site.
Chlorine	For bacteria control in cooling towers	Produced via the chloralkali process at Botany, with sodium hydroxide produced as a by-product.
Lime	Cooling water softener	Depending on the location of the power station, lime may be sourced from a range of kilns at Marulan or Tamworth.
Sodium hydroxide	Used for anion resin regeneration	Sodium hydroxide is produced in the chloralkali process at Botany.
Ammonia	Used in the steam condensate line to counter carbonic acid formation and to raise pH	Produced at the Incitec plant on Kooragang Island (Newcastle).
Sulfuric acid	Used in cation resin regeneration	Based on Mt Isa sulfuric acid plant.

2.1.6 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^[18].

2.2 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 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 operation. 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 NSW generators use higher ash coals produced as a co product during the production of export coals, 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.

2.3 Data quality

Estimated data accuracies for key items in the life cycle analysis are given in Table 12, together with the overall impacts on the GGE values.

Table 12 Data accuracies of key items

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

2.4 Allocation

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

2.5 Impact assessment

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

- Resource energy
- Fresh water
- GGE (CO₂-e)
- NO_x

- SO_x
- Particulates
- Solid waste
- All available NPI data for power generation, coal mining, *etc.*

2.5.1 National Pollutant Inventory ^[14]

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.

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

Table 13 lists these 90 substances as well as the associated reporting thresholds, which are 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 from 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 (NH₃) and the ammonium ion (NH₄⁺) 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 and its 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 13 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

Substance	Category	Substance	Category
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
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

Substance	Category	Substance	Category
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 category thresholds are shown in Table 14.

Table 14 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	Consume 2,000 t per year of fuel, or 60,000 MWh, or at any time within the period consumed 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 New South Wales transmission grid is shown in Table 15. 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 15 Resource consumption per MWh of electricity from the NSW transmission grid (no SMHEA or interstate purchases)

Resource	Amount	Unit	Comment
Biomass	1.0	kg	Supplement to coal-fired boilers at Liddell and Bayswater power stations
Coal	0.431	t	Coal fired boiler fuel
Coal seam methane	0.089	GJ	Used at the Appin/Tower power plants
Crude oil	0.083	GJ	For coal-fired boiler start-up, gas turbine peaking stations and transport fuel
Electricity	0.0035	MWh	Renewable power input to the grid
Limestone	0.0001	t	Lime production for pH adjustment of power station cooling water
NG	0.18	GJ	Gas fired peaking stations and ammonia/ammonium nitrate production
Fresh water	1.51	m ³	Primarily for power station evaporative cooling and boiler feedwater
Salt water	0.0022	m ³	Chloralkali plant (chlorine and sodium hydroxide for water treatment)

The largest consumables per MWh of power produced by the NSW grid are black coal (431 kg) and fresh water (1,500 kg). Chemical feedstocks, natural gas, 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 (excluding SMHEA) contribute 3.5 kWh per MWh of electricity supplied by the electricity grid.

3.2 Impact assessment values

The totals for electricity sent-out from power stations, and electricity available to the transmission and distribution grids, are shown in Table 16. This reflects the losses due to transmission and distribution which are approximately 3% and 6%, respectively.

Table 16 - Total electricity flow through New South Wales grid from major generators

Total sent out electricity (GWh)	Electricity available from transmission grid (GWh)	Electricity available from distribution grid (GWh)
60,729	59,298	55,995

A summary of the results for the production of 1 MWh of electricity is shown in Table 17.

*Table 17 Impact assessment values for 1 MWh of NSW grid electricity
(no interstate purchases)*

Parameter	Transmission grid (no SMHEA)	Transmission grid (with SMHEA)	Distribution grid (no SMHEA)	Distribution grid (with SMHEA)	Comment
Inputs					
Resource energy (GJ)	10.67	10.27	11.30	10.88	94.4% coal, 1.7% NG, 0.77% crude oil, 0.83% coal seam methane
Fresh water (m ³)	1.51	1.45	1.59	1.53	Primarily for evaporative cooling
Outputs					
GGE (kg CO ₂ -e)	967	932	1025	987	94.3% from power stations, 5.6% from coal mining
NO _x (kg)	2.40	2.31	2.55	2.45	98.6% from fossil fuel power generation
SO _x (kg)	4.33	4.17	4.59	4.41	99.9% from fossil fuel power generation
Particulates (kg)	0.15	0.15	0.16	0.16	52.2% from power generation, 47.7% from open cut coal mining
Solid waste (kg)	104	100	111	106	99.7% from power generation

The difference between 1 MWh of electricity from the transmission and distribution grids is the distribution loss of 5.57% (average) in the distribution system. With purchases from the SMHEA, the impacts for both the transmission and distribution grids are reduced by a factor close to the percentage of SMHEA purchases of the grid. No current data for New South Wales purchases from SMHEA is available, so it is assumed that NSW purchased the same portion of SMHEA's output as for the latest available data (2001). This results in New South Wales consuming approximately 62.5% of SMHEA's output in CY2003, equating to around 3.8% of total generated electricity in New South Wales.

In summary:

- The resource energy consumption for the NSW transmission grid is dominated by coal (94.4%), with only small contributions from natural gas, oil and coal seam methane.
- Fresh water is consumed primarily by the inland coal fired power stations for condenser cooling. For the NSW transmission grid (no SMHEA) every MWh of electricity generated consumes on average, 1.5 m³ of fresh water. This equates to a total consumption of around 84 GL per annum.
- Greenhouse gas emissions are dominated by emissions from coal fired power stations (94.3%), followed by coal mining (5.6%).

- 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 particulates emitted.

When the LCA results are projected out to a New South Wales 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 18 shows the projected emissions from the NSW grid, with comparison to the State total.

Table 18 Projected emissions from NSW power generation compared to State total^[14,26,27]

Parameter	Transmission grid (no SMHEA) 2003 (per MWh)	Distribution grid (no SMHEA) 2003 (per MWh)	Total from NSW grid 2003 (per annum)	Total NSW - all sources (per annum)	% of State
Resource energy	10.67 GJ	11.3	632.9 PJ	1,533 PJ ¹	41.3
Fresh water	1.42 m ³	1.51	84.2 GL	9,425 GL ²	0.9
GGE	967 kg CO ₂ -e	1025	57.4 Mt	151 Mt ³	38.0
NO _x	2.4kg	2.55	143 kt	305 kt ⁴	46.9
SO _x	4.33 kg	4.59	257 kt	300 kt ⁴	85.7
Particulates	0.15 kg	0.16	9.1 kt	73 kt ⁴	12.5

1. 2003/4 ABARE data
2. 2001 data most recent available
3. 2002 data is most recent
4. Weighted average 2003 and 2004 NPI data

The comparison shows that a significant proportion of all impacts in New South Wales 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 NSW transmission grid (no SMHEA). The data is presented with the top bar graph representing 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 Bayswater, Eraring, Liddell, Mt Piper, Vales Point and Wallerawang (these closely follow the grid contributions). Underground coal mines, smaller power stations, natural gas and oil processes, (represented as other in the pie chart), contribute to a lesser extent.

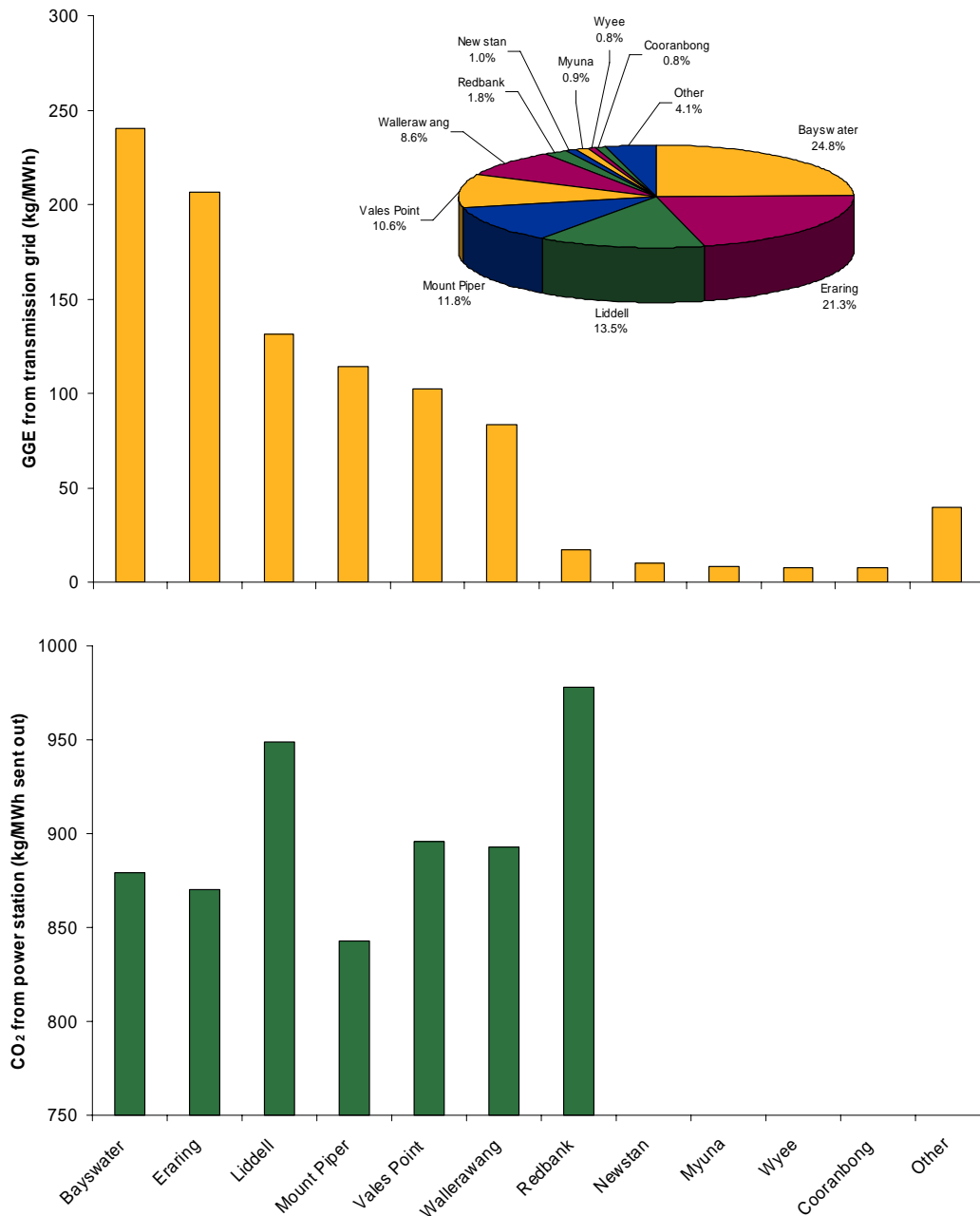


Figure 2 Breakdown of GGE per MWh of electricity from the NSW transmission grid (no SMHEA)

NO_x emissions (Figure 3) are primarily from the large coal fired power stations with Bayswater, Eraring, Mt Piper and Liddell the major contributors. Smaller contributions are from coal mining and transportation.

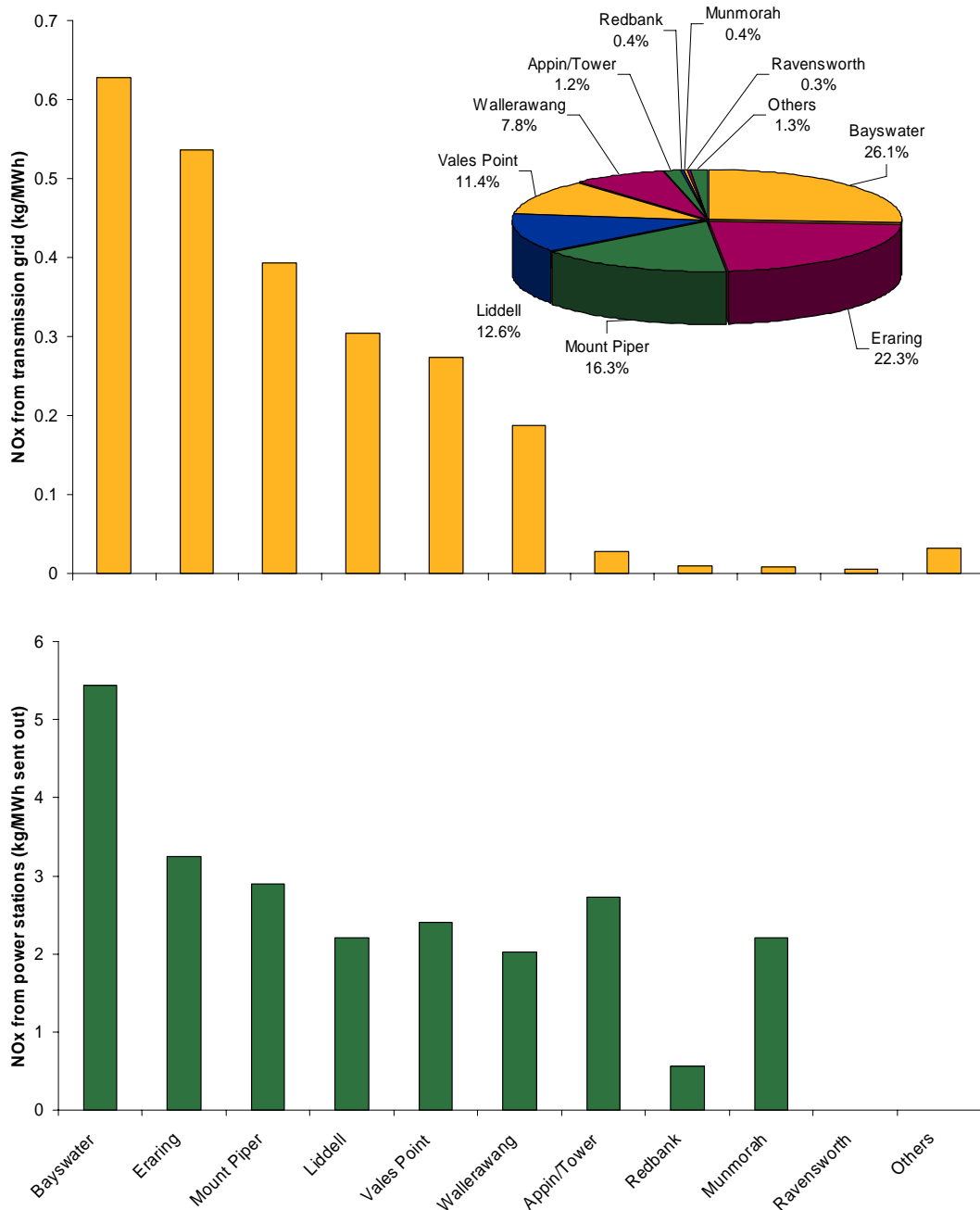


Figure 3 Breakdown of NO_x per MWh of electricity from the NSW transmission grid (no SMHEA)

SO_x emissions (Figure 4) are again primarily from the large coal fired power stations with Bayswater, Eraring, Liddell and Mt Piper the major contributors. SO_x emissions from sources other than power stations are insignificant.

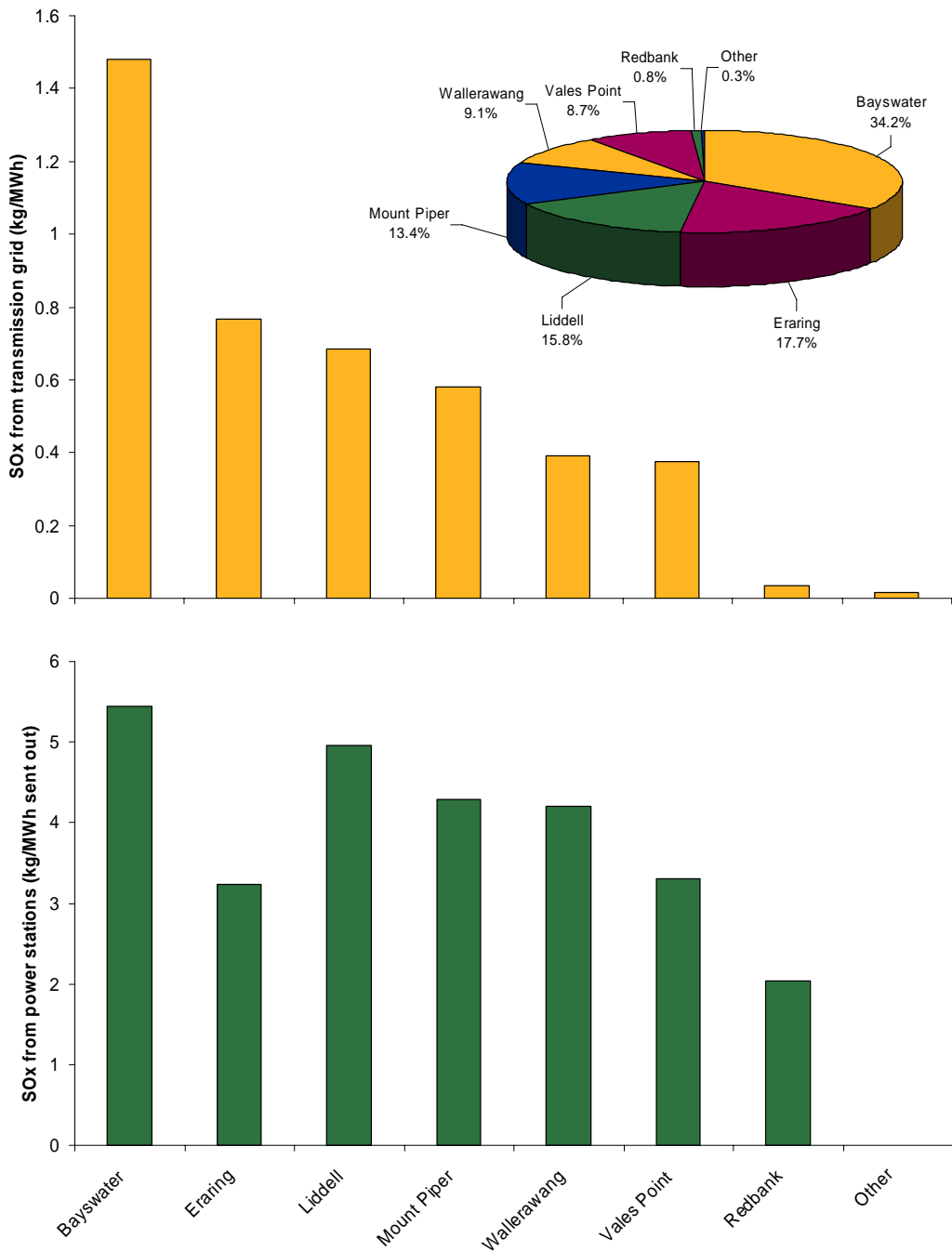


Figure 4 Breakdown of SO_x per MWh of electricity from the NSW transmission grid (no SMHEA)

For particulates, (Figure 5), five of the top ten emitters are open cut coal mines. Large coal fired power stations, especially those with electrostatic precipitators (Wallerawang, Vales Point), are significant contributors to particulate emissions per MWh of electricity from the NSW transmission grid.

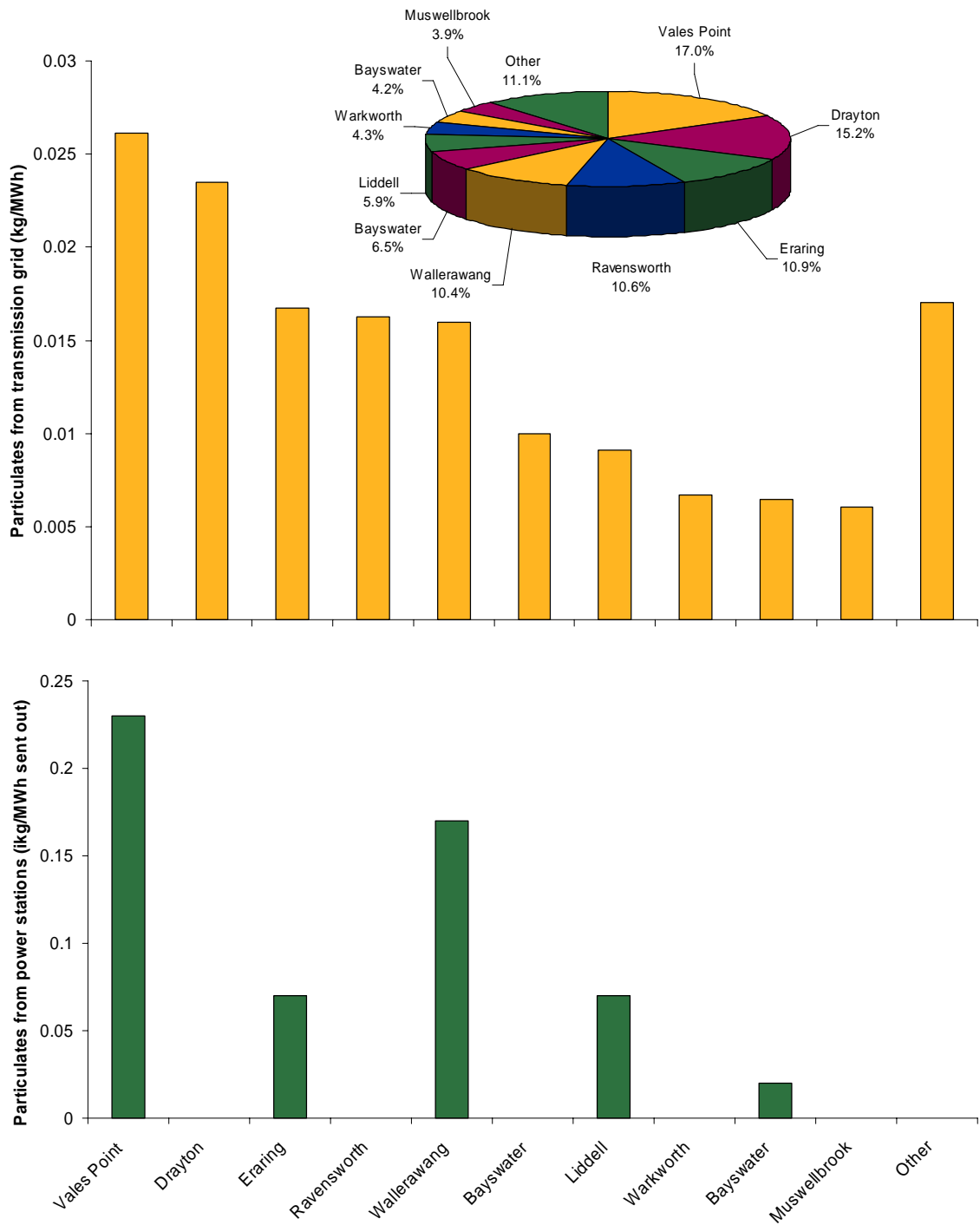


Figure 5 Breakdown of particulate emissions per MWh of electricity from the NSW transmission grid (no SMHEA)

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

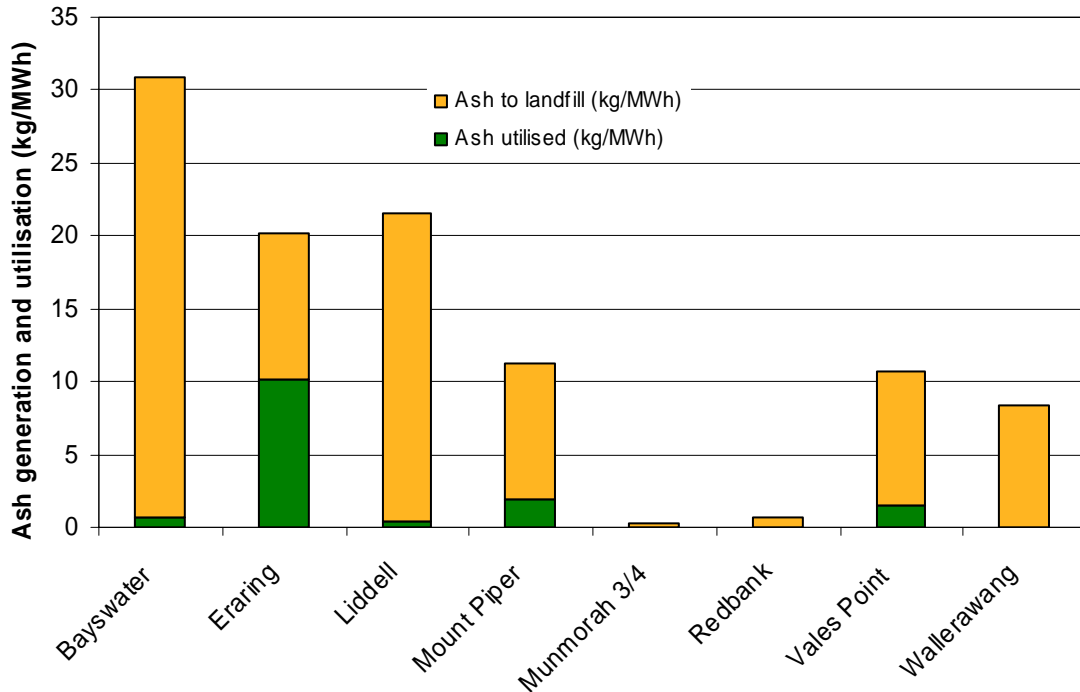


Figure 6 Breakdown of ash generation and utilisation per MWh of electricity from the NSW transmission grid (no SMHEA)

The rate of utilisation of coal ash (fly and bottom ash) in New South Wales is approximately 14.1%. This is equal to a utilisation rate of approximately 14.7 kg/MWh or an annual use of around 870,000 tonnes of ash from over 6.2 million tonnes of ash produced.

The exact percentage of ash used in cement in New South Wales is unknown. The percentage of power station generated ash utilised in Australia in 2003 was 18.8%. 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)^[28].

3.2.2 National Pollutant Inventory

The National Pollutant Inventory (NPI) data per MWh of electricity from the NSW transmission grid (no SMHEA) for the period YEJ 2001 are given in Table 19, Table 20 and Table 21, 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 19 NPI emissions to air per MWh of electricity from the NSW transmission grid (no SMHEA)

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
1,3-butadiene (vinyl ethylene)	8.20×10^{-11}	0.005	Oil refining
acetaldehyde	2.79×10^{-09}	0.165	1 coal mine, 1 power station, oil refining
acetone	1.00×10^{-12}	~ 0	Oil refining
ammonia (total)	1.06×10^{-06}	62.9	7 power stations, oil refining
antimony & compounds	8.00×10^{-11}	0.005	6 coal mines, 1 power station
arsenic & compounds	4.43×10^{-09}	0.263	13 coal mines, 8 power station, oil refining
benzene	1.00×10^{-08}	0.594	2 coal mines, 1 power station, oil refining
beryllium & compounds	1.52×10^{-09}	0.090	7 coal mines, 8 power stations
boron & compounds	6.26×10^{-06}	371	9 coal mines, 7 power stations
cadmium & compounds	1.48×10^{-09}	0.088	6 coal mines, 8 power station, oil refining
carbon disulfide	6.18×10^{-10}	0.037	1 power station
carbon monoxide	1.47×10^{-4}	8,720	13 coal mines, 10 power stations
chloroform (trichloromethane)	2.86×10^{-10}	0.017	1 power station
chromium (III) compounds	2.96×10^{-08}	1.75	9 coal mines, 8 power stations
chromium (VI) compounds	4.16×10^{-09}	0.247	6 coal mines, 7 power stations, oil refining
cobalt & compounds	3.28×10^{-09}	0.195	14 coal mines, 4 power stations, oil refining
copper & compounds	2.28×10^{-08}	1.35	9 coal mines, 8 power stations
cumene (1-methylethylbenzene)	4.62×10^{-09}	0.274	6 power stations
cyanide (inorganic) compounds	1.02×10^{-07}	6.05	2 power stations, oil refining
cyclohexane	5.20×10^{-10}	0.031	1 power station, oil refining
di-(2-ethylhexyl) phthalate (DEHP)	3.53×10^{-10}	0.021	1 power station
dibutyl phthalate	2.67×10^{-10}	0.016	1 power station
ethylbenzene	4.64×10^{-10}	0.028	1 power station, oil refining
Fluoride compounds	1.82×10^{-05}	1,080	1 coal mine, 8 power stations
fluorides	9.24×10^{-08}	5.48	13 coal mines, oil refining
formaldehyde (methyl aldehyde)	2.34×10^{-06}	139	Oil refining
hydrochloric acid	1.39×10^{-04}	8250	8 power stations
lead & compounds	2.18×10^{-08}	1.29	16 coal mines, 8 power stations, oil refining
manganese & compounds	1.29×10^{-07}	7.65	9 coal mines, 4 power stations
mercury & compounds	5.80×10^{-09}	0.344	9 coal mines, 8 power stations, oil refining
methanol	1.00×10^{-12}	~ 0	Oil refining

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
methyl ethyl ketone	1.45×10^{-08}	0.861	1 power station, oil refining
methyl isobutyl ketone	7.61×10^{-10}	0.045	1 power station
methyl methacrylate	9.50×10^{-11}	0.006	1 power station
n-hexane	2.66×10^{-09}	0.158	2 power stations
nickel & compounds	2.32×10^{-08}	1.37	9 coal mines, 8 power stations, oil refining
oxides of nitrogen	2.32×10^{-3}	142,000	14 coal mines, 10 power stations
particulate matter 10.0 um	1.54×10^{-4}	9,100	14 coal mines, 10 power stations
phenol	8.20×10^{-11}	0.005	1 power station, oil refining
phosphorus (total)	2.30×10^{-11}	0.001	Oil refining
polycyclic aromatic hydrocarbons	6.03×10^{-09}	0.358	8 coal mines, 9 power stations, oil refining
selenium & compounds	1.29×10^{-07}	7.60	8 coal mines, 3 power stations
styrene (ethenylbenzene)	6.10×10^{-11}	0.004	1 power station, oil refining
sulfur dioxide	4.33×10^{-3}	257,000	14 coal mines, 10 power stations
sulfuric acid	4.66×10^{-05}	2,760	8 power stations
tetrachloroethylene	2.09×10^{-10}	0.012	1 power station
toluene (methylbenzene)	5.73×10^{-08}	3.40	1 coal mine, 4 power stations, oil refining
total nitrogen	3.79×10^{-09}	0.225	Oil refining
total volatile organic compounds	1.96×10^{-05}	1,160	8 coal mine, 11 power stations
trichloroethylene	2.96×10^{-10}	0.018	1 power station
xylenes (individual or mixed isomers)	2.24×10^{-08}	1.33	1 coal mine, 4 power stations, oil refining
zinc & compounds	3.96×10^{-08}	2.34	9 coal mines, 4 power stations, oil refining

Table 20 NPI emissions to water per MWh of electricity from the NSW transmission grid (no SMHEA)

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
ammonia (total)	1.30×10^{-06}	76.8	3 power stations
arsenic & compounds	1.41×10^{-09}	0.084	4 coal mines, 1 power station
boron & compounds	2.51×10^{-10}	0.015	2 coal mines, 1 power station
cadmium & compounds	1.60×10^{-11}	0.001	1 power station
chlorine	7.67×10^{-07}	45.5	1 power station
chromium (III) compounds	4.90×10^{-10}	0.029	1 coal mine, 1 power station
chromium (VI) compounds	8.27×10^{-10}	0.049	3 coal mines, 2 power stations
cobalt & compounds	1.40×10^{-11}	0.001	1 power station
copper & compounds	9.10×10^{-11}	0.005	1 coal mine, 2 power stations
fluoride compounds	8.44×10^{-10}	0.050	1 power station
fluorides	4.30×10^{-11}	0.003	2 coal mines
lead & compounds	2.52×10^{-09}	0.149	7 coal mines, 2 power stations
manganese & compounds	8.61×10^{-10}	0.051	4 coal mines, 2 power stations
nickel & compounds	9.10×10^{-11}	0.005	1 coal mine, 1 power station
sulfuric acid	2.89×10^{-08}	1.71	1 sulfuric acid plant
total nitrogen	2.55×10^{-07}	15.1	1 coal mines, 1 power station
zinc & compounds	8.80×10^{-11}	0.005	2 coal mines, 1 power station

Table 21 NPI emissions to land per MWh of electricity from the NSW transmission grid (no SMHEA)

Emission Type	Emission (t/MWh)	Emission (t/a)	Reporting facilities
antimony & compounds	4.20 x 10 ⁻⁰⁹	0.249	1 power station
arsenic & compounds	3.21 x 10 ⁻⁰⁹	0.191	1 power station
beryllium & compounds	2.45 x 10 ⁻⁰⁹	0.145	1 power station
cadmium & compounds	1.74 x 10 ⁻⁰⁹	0.103	1 power station
chromium (III) compounds	1.13 x 10 ⁻⁰⁸	0.671	1 power station
chromium (VI) compounds	1.92 x 10 ⁻⁰⁹	0.114	1 power station
cobalt & compounds	3.46 x 10 ⁻⁰⁸	2.05	1 power station
copper & compounds	6.08 x 10 ⁻⁰⁸	3.60	1 power station
fluorides	1.38 x 10 ⁻¹⁰	0.008	2 coal mines
lead & compounds	5.04 x 10 ⁻⁰⁸	2.99	1 power station
manganese & compounds	1.44 x 10 ⁻⁰⁷	8.57	2 coal mines, 1 power station
mercury & compounds	2.98 x 10 ⁻¹⁰	0.018	1 power station
nickel & compounds	2.09 x 10 ⁻⁰⁸	1.24	1 power station
zinc and compounds	9.37 x 10 ⁻⁰⁸	5.55	1 coal mine, 1 power station

The results show that per MWh of electricity supplied by the NSW transmission grid, small amounts of most emission types are emitted; of the order of micrograms (*eg* acetone) up to kilograms (*eg* NO_x, SO_x). However, when these emissions are converted to a per annum basis, the quantities range from 0.1 kg to 257,000 tonnes.

Of the reported emissions in NSW, power generation represents a significant proportion for some types. For example, the total reported NO_x emissions in NSW on the NPI for the year ending July 2003 were approximately 310,000 tonnes. The present study has shown that emissions of NO_x associated with power generation from the NSW transmission grid for the year ending January 2003 were 142,000 tonnes or over 45% of the total reported emissions. Currently available NPI data 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 that 13% is used as cement extender) and also for the scenario assuming that 100% of coal ash produced is used as a cement extender (see Table 22).

Table 22 Displacement credits for coal ash utilisation as a cement extender for 1 MWh of electricity from the NSW transmission grid (no SMHEA or interstate imports)

Parameter	0% displacement	13% (current displacement assuming all ash to cement)	100% (maximum potential displacement)
Resource energy (GJ)	10.67	10.58	10.05
GGE (kg CO ₂ -e)	968	953	859
NO _x (kg)	2.41	2.38	2.21
SO _x (kg)	4.33	4.32	4.28

The factors used to calculate these credits come from a previously completed study on cement production using 1 tonne as the functional unit. These factors are shown in Table 23. It is important to note that the assumed replacement rate is 1:1 therefore reducing cement production emissions and resource consumption by approximately 50%.

Table 23 Impact assessment values for cement production

Parameter	Factor
Resource energy (GJ)	5.9
GGE (kg CO ₂ -e)	1050
NO _x (kg)	1.89
SO _x (kg)	0.46

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 CY2003 numbers as a percentage of those from 2001.

Table 24 Comparison of inputs and outputs from the New South Wales electricity grid (comparisons with previous study)

Parameter	2001		CY2003		Difference ^a (%)
	Transmission grid	Distribution grid	Transmission grid	Distribution grid	
Inputs					
Resource energy (GJ)	10.75	11.38	10.67	11.30	- 0.7%
Fresh water (m ³)	1.11	1.17	1.42	1.51	+ 27.9%
Outputs					
GGE (kg CO ₂ -e)	974	1031	968	1025	- 0.6%
NO _x (kg)	2.92	3.09	2.40	2.55	- 17.8%
SO _x (kg)	4.14	4.38	4.33	4.59	+ 4.6%
Particulates (kg)	0.19	0.2	0.15	0.16	-21.1 %
Solid waste (kg)	111	117	104	111	- 6.3%

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

Key findings are:

- Overall system efficiency has improved since 2001, though marginally. This is shown by the decrease in resource energy consumption per MWh output. The reasons behind such a small differential were that no power stations were commissioned or decommissioned in the time between studies, and that the percentage of total output for each power station remained reasonably constant over the period.
- Water consumption was seen to increase quite substantially over the past three years on a MWh basis. This was due to Macquarie Generation reporting water consumption at a much higher level in this period for their Bayswater and Liddell power stations. As these two stations are responsible for around 40% of the entire grid, this had a significant effect on total water consumption.
- There was very little change in the greenhouse gas intensity of the grid, with a decrease of only 0.6%. This small decrease was in line with the decrease in required energy resource per unit of output. It is expected that, if the NSW government is successful with its program to increase gas generated electricity, greenhouse gas intensity will decrease significantly.
- NO_x emissions from power generation contribute around 47% of the state total for all sources, (c.f. 43% in 2001). There has, however, been a considerable decrease in NO_x emissions per MWh of output over this time. The 18% reduction (2.92kg/MWh to 2.4kg/MWh) in NO_x emission intensity has been the result of reductions in NO_x intensity from most of the major power stations contributing to the grid.

- Electricity generation made a smaller contribution to the state total for SO_x emissions as a percentage in 2003 than it did in 2001. However, the SO_x intensity of the grid increased by 4.6%. This is the result of the four major contributors to the grid, Bayswater, Liddell, Eraring and Mount Piper, reporting higher intensities in this period. It is also noteworthy that Appin Tower power station (utilising coal bed methane) had a SO_x intensity three times greater than for the next highest polluter in 2001. This was erroneous data resulting in a higher than actual value in the 2001 data. It is likely that the increase from 2001 to CY2003 is greater than the 4.6% reported.
- Particulate emissions for the NSW grid are evenly spread between coal mines and power stations, with 52.2% coming from power stations and 47.7% from coal mines. The fact that power stations hold the dominant share is a result of the use of electrostatic precipitators at Wallerawang and Vales Point power stations. Overall, the emission per MWh of generation has decreased, as well as the grid's share of the state total.
- Transmission and distribution losses for 2003 were unavailable. The present study used the 1997 value published by the ESAA of 2.7% for transmission loss. The current value for distribution loss was obtained from the ESAA and was 5.6% for 2003, (compared to 5.5% in 2001).

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