Energy Use in the Provision and Consumption of Urban Water in Australia and New Zealand

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ACRONYMS AND ABBREVIATIONS

ABARE   The Australian Bureau of Agricultural and Resource Economics

ABS   Australian Bureau of Statistics

AGO   Australian Greenhouse Office

ANZSIC   Australian and New Zealand Standard Industry Classification

CO_2-e   Carbon Dioxide Equivalent – An index that integrates various GHGs associated with a system by using the Global Warming Potential of each to weight the contributions

CSIRO   Commonwealth Scientific and Industrial Research Organisation

EE   Embodied Energy

GHG   Greenhouse Gasses (GHG's common to the water industry include Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O).

GJ   Giga Joule (10^9 Joules); Note 1 GJ/ML = 1 MJ/m^3 = 0.277 kwh/m^3)

GWh   Gigawatt hour (10^6 kWh). (Note that 100 GWh energy generated in Australia's eastern energy grid releases approximately 100,000 t of CO_2-e)

HH   Household (on average containing approximately 2.5 people)

HWS   Hot water system

kWh   Kilowatt hour (3.6×10^6 J)

L/(cap*a)   Litre per capita (person) per year

L/(cap*d)   Litre per capita (person) per day

PJ   Peta Joule (10^{15} Joules)

SEQ   South East Queensland

t   Metric Tonne (1000 kg)

TJ   Tera Joule (10^{12} Joules)

WSAA   Water Services Association of Australia

DEFINITIONS

Centralised System: Large scale system for the provision of water and wastewater services provided by Government regulated water utilities.

Decentralised System: The sourcing, treatment and provision of water services at or near the point of use. This may include onsite systems, such as rainwater tanks, owned and operated by the householder.

Energy Intensity: A measure of the energy required to pump or treat a unit volume of water or wastewater.

Full fuel cycle (FFC) emission factor: Describes the quantity of emissions released per unit of energy for the entire fuel production and consumption chain. For fuel combustion, the full fuel cycle emission factor is the sum of the direct emission factor for the fuel and the specific 'scope 3' emission factor for the emissions from the extraction, production and transport of the fuel. For the consumption of purchased electricity, the full fuel cycle emission factor is the sum of the 'scope 2' indirect emission factor for emissions from fuel combustion at the power station and the specific 'scope 3' emission factor for emissions from the extraction, production and transport of that fuel and for emissions associated with the electricity lost in transport (Department of Climate Change 2008).

Operational Energy: Energy used for the operation of the water supply and wastewater system (as distinct to embodied or Life Cycle energy requirements).

Primary Wastewater Treatment: The first major treatment process in a wastewater treatment facility, principally designed to remove substantial amount of suspended matter. Typical processes may include clarification (to separate liquid and solids), grease removal and screens (WSAA and NWC 2007).

Secondary Wastewater Treatment: Typically, a biological treatment process that is designed to remove 85% of the Biological Oxygen Demand and influent suspended solids. Some nutrients may be removed and ammonia may be converted to nitrate. Secondary treatment processes may include sand filtration, disinfection, a polishing step (to lower suspended solids and bacterial levels), activated sludge processes, anaerobic and aerobic processes, biological filters and lagoons (aerated, facultative, maturation and polishing) (WSAA and NWC 2007).

Tertiary Wastewater Treatment: Principally designed to remove nutrients, such a phosphorous and nitrogen. A high percentage of effluent suspended solids (typically >95%) are also removed. Typical tertiary wastewater treatment processes may include biological nutrient removal plants, chemical dosing of secondary plants for nutrient removal (including lagoons), enhanced pond treatment systems for nutrient removal, reverse osmosis and advanced filtration systems, membrane bioreactors and secondary treatment plus grass plots or wetlands for nutrient removal (WSAA and NWC 2007).

Treatment Energy: Energy necessary to treat water or wastewater including energy necessary to pump/pressurise water (e.g. for reverse osmosis); and to move water on-site from one treatment process to another.

Transport Energy: Energy necessary to move water, wastewater or recycled water to and from particular sites (e.g. to point of use, commencement of treatment, or from final treatment through to disposal/release).

Urban System: The physical economy of a city that includes all the flows of energy, water and materials required to sustain the population. For this report urban systems energy use was estimated as the pro-rata proportion of total energy use for the State in which the city is located.

EXECUTIVE SUMMARY

This report is the outcome of a Water Services Association of Australia (WSAA) and CSIRO initiative to improve the understanding of energy use by wholesale and retail water utilities and place this use in context with energy use in the heating of water and also in the urban system. The report has been prepared proactively to meet an increasing need for information on options to improve energy efficiency and mitigate greenhouse gas emissions from all sectors, including the provision of urban water services.

This report analyses the operational energy used by water utilities for both water supply and wastewater disposal. It attempts to place that energy use in context with the energy needs for residential hot water and the total energy requirements for supporting 7 major cities in Australia and New Zealand. The analysis of operational energy for urban water services is based on a survey of 10 water utilities in which detailed data were provided on energy consumption in all components of the urban water cycle. Additional information was sourced from the literature and other data reviews. The conclusions of this report are thus dependent on the accuracy and reliability of this data.

Additional information on the energy required for domestic hot water heating and the total energy required to support each city was also sourced. The estimates of energy use for residential water heating were based on first principle calculations together with data derived from hot water consumption estimates. Australian Bureau of Statistics data were used to estimate total energy use in urban systems which was taken as the pro-rata estimate of State-wide energy use. Brief consideration was also given to embodied energy in infrastructure and greenhouse gas emissions associated with all energy uses. Fugitive emissions were not analysed in this report.

The report also describes a number of possible future profiles of urban water systems and estimates the associated additional energy required of these future profiles. Sydney, Melbourne, Brisbane, Gold Coast, Adelaide and Perth are expected to grow from their current population of 12.1 million to some 15.8 million by 2030. The future water supply needs associated with this growth were based on three possible levels of per capita residential water supply – 150, 225 and 300 L/cap/day.

Based on these numbers, the extra water resources required in 2030 for these cities ranges from negligible demand for additional water (at 150 L/cap/day residential use) through to approximately 1,400 GL/annum at 300 L/cap/day residential water demand. However, the bottom end figures of 150 L/cap/day are representative of a city under severe water restrictions and may not be socially or even economically acceptable in the long term. The analysis also assumes that the extra water required under these scenarios can be supplied either by a mixture of new sources (40% desalination, 40% reuse and 20% new sources) or by 100% desalination. The energy implications of these possible futures were evaluated and compared to projected energy for hot water provision and for total urban systems.

The key findings from these analyses are:

- The total energy use for water and wastewater services of the six Australian cities studied was 7.1 PJ/annum in 2006-07. This figure represents less than 20% of the energy used for domestic water heating and about 0.2% of total urban energy use.

- Energy use for water and wastewater services varies significantly across all cities. Local factors including topography and water sources are major factors influencing energy use.

- Pumping water long distances and/or against gravity uses substantial amounts of energy. The need to pump water from rivers some distance away to ensure security of supply in a time of low storage levels contributes significantly to current energy use in some cities. It is possible that in some circumstances sourcing recycled and desalinated water closer to the city could require less energy. However further research is required into long distance pumping efficiency.

- Treating wastewater to a tertiary standard requires substantial energy compared to primary or secondary treatment. On average, energy intensity doubles between primary and secondary treatment and doubles again between secondary and tertiary treatment. If tertiary treatment of wastewater is required, then reuse opportunities may become more cost-effective as the additional energy required for reuse may be relatively minor depending on post-treatment energy requirements.

- Imported electricity is the dominant source of energy-related greenhouse emissions for the water industry (In this survey an average of 76% of energy used by water utilities (water service providers) was sourced from standard electricity), therefore efforts to minimise energy-related greenhouse emissions need to focus attention on the use of imported electricity. The use of biogas and sourcing energy from sources other than coal based electricity will significantly reduce greenhouse gas emissions. Maximising the application of other energy generation options, such as mini-hydro schemes, can also contribute.

- Residential hot water heating consumes on average 1.3% of total energy used in Australian cities or 27% of total household energy use. Residential hot water uses on average 6.5 times the energy that is used to deliver urban water services, this ratio ranging from 4.7 in Adelaide to 11.2 in Melbourne.

- A 20% reduction in the use of hot water or an equivalent increase in the efficiency of hot water systems would completely offset the total energy currently used for water service provision.

- Energy used during industrial and commercial use of waters (e.g. water heating) are anticipated to be of similar order of magnitude to the energy requirements for residential water heating however minimal data is available to verify this. This represents a key knowledge gap.

- Forward projections to 2030 indicate that, if all new sources were supplied by 100% desalination (the extreme case), at 225 L/capita/day residential use, the total energy required for urban water services would jump from the current 7.1 PJ/annum to 21 PJ/annum (a 200% increase) and for the 300 L/capita/d residential water use would lead to an increase from 7.1 PJ/annum to 36 PJ/annum (a 400% increase).

- Forward projections to 2030 indicate that, if new sources were supplied by a mixture of sources (40% desalination, 40% reuse and 20% additional surface water supplies), at water consumption rates of 225 L/capita/day, the total energy required for urban water services would grow from the current 7.1 PJ/annum to 16 PJ/annum (a 130 % increase) and for the 300 L/capita/d scenario, from 7.1 PJ/annum to 26 PJ/annum (a 260% increase).

- If consumption is reduced to 150 L/capita/day, then no new energy would be required as minimal additional water would be required presuming current yields are maintained.

- Depending on per-capita water usage and the water supply option adopted, the energy consumption by water utilities in 2030 would represent between 0.4 to 0.7% of the total energy used in Australian cities in 2030. It would also represent between 23 and 45% of energy used for domestic hot water.

- If a mixture of reuse (40%), desalination (40%) and new water sources (20%) were used to meet an average residential consumption of 225 L/capita/day, an improvement in the efficiency of residential water heating of 13.5% would be required to offset the extra energy required.

- Existing information, although sparse, indicates that operational energy is significantly greater than the annualised energy embodied in urban water infrastructure.

Although this report highlights the relatively small contribution of urban water services to total energy consumption, it also identifies that, unless future water demand is drastically curtailed, energy requirements for future water supplies will rise approximately 400 percent. In order to minimise the

greenhouse impacts of this extra energy use, water utilities should continue to make concerted efforts to minimise their use of energy and greenhouse gas emissions. However, as illustrated by the example of domestic hot water, efforts to reduce energy use associated with residential use of water have much greater scope for emission reductions. Given water utilities are in a position to influence this larger pool of energy use, the implications of water management strategies on the energy associated with end-use of water should be considered.

Major recommendations which arise from this report are that the water industry should:

- Continue with a detailed mapping of its own internal energy use and the associated greenhouse gas implications in order to accurately understand its situation;

- Continue with a program of improving energy use efficiency in its own operations and seek to influence improvements in energy use efficiency in the domestic environment where the scope for gains may be substantially larger;

- Develop and implement schemes for the internal generation of energy (e.g. via biogas generation or mini-hydro schemes) and, where needed, seek imported electricity only from low greenhouse gas emission sources;

- Assess all aspects of energy consumption associated with projected new water sources, particularly those associated with pumping water long distances and/or against gravity, and factor these into water supply planning;

- Improve monitoring and reporting of end-use energy (particularly residential hot water) is recommended. Such information would help confirm the magnitude of current energy use associated with water use and thereby improve estimates of the influence of water supply options on energy use;

- Improve definitions of energy required for "treatment" and "transport" of water and wastewater are required. These definitions are particularly important to clarify the influence of pumping at treatment plant sites (i.e. between the different treatment processes);

- There is generally little information available regarding the energy use of decentralised systems (e.g. rainwater tanks, backyard bores). The influence of increased uptake of decentralised water supply options on energy warrants further analysis.

- Relatively little data exists for fugitive greenhouse gas emissions in the water cycle. Compilation and analysis of such data is warranted.

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1. INTRODUCTION

This report is the outcome of a Water Services Association of Australia (WSAA) and CSIRO initiative to improve the understanding of energy use by wholesale and retail water utilities and place this use in context with energy use in the heating of water and also in the wider urban system. The report has been prepared proactively to meet an increasing need for information on options to improve energy efficiency and mitigate greenhouse gas emissions from all sectors, including the provision of urban water services.

This report focuses on placing the water industry's energy use in context for several reasons. The water industry is one of the first industries to be significantly impacted by climate change as reduced rainfall and declining inflows places extreme pressure on traditional water supplies. The industry is undertaking many proactive measures to increase energy efficiency, reduce greenhouse gas emissions and generate energy from renewable sources, however new sources of water such as desalination and recycled water are energy intensive compared to traditional supplies. Increased concern about climate change and the need for greenhouse gas emission abatement options has focused attention on water-related energy use and greenhouse gas implications. However, in many cases the debate is option specific, lacks comparable data for analysis and does not consider water-related energy use in the context of energy use in homes and businesses as well as the wider economy.

It is argued here that widening the debate will offer greater scope for 'system-wide' reductions in energy use and greenhouse gas emissions. Water utilities, as government owned entities, have a number of policy options available to influence future water use. Consequently the opportunity exists to influence the wider, more substantial pool of energy associated with the end-use of water. Future water strategies which consider water efficiency as well as the energy implications of water use will offer far greater scope for reductions than consideration of energy use by utilities alone.

1.1   Background to this study

Urban water service provision includes the planning and delivery of water supplies for residential, commercial and industrial uses as well as the collection, treatment and disposal or recycling of wastewater. Energy is used throughout the urban water cycle including the pumping and treatment of water and wastewater.

Energy requirements vary significantly from city to city depending on local factors such as topography, the location and quality of water sources, pipe dimensions and configurations and treatment standards required. However water industry decisions on operational strategies and technology selection can also significantly influence energy use. Energy use in water services provision is increasing with increased treatment standards, use of more marginal water qualities and increased pumping distances for raw and treated waters (Chartres 2005; Zakkour et al. 2002).

Most Australian cities are currently implementing a wide range of integrated water management initiatives due to reduced rainfall and declining water storage inflows. These initiatives include recycling, desalination or development of new surface and groundwater supplies. There is also a focus on increased water use efficiency particularly for residential use. Decentralised water supply options are also being encouraged and household water supply options such as rainwater tanks have been encouraged and large numbers installed in many cities.

The majority of proposed new water sources are more energy intensive than traditional sources (Medeazza and Moreau 2007). The increment in energy use creates a real dilemma because it contributes further greenhouse gas emissions and consequently contributes to ongoing climate change. In addition, energy generation itself requires a constant source and large amount of water (particularly for coal fired power stations) which can further compete with water needs of cities.

Simultaneously addressing urban water cycle issues while reducing energy use or greenhouse gas emissions represents a challenge that will require fresh planning concepts and technologies coordinated across both the water and energy cycles.

To date limited analysis of the energy implications of water strategies has been undertaken and energy use is rarely mentioned in most urban water strategies (DSE 2006; Qld Government 2006; Water Corporation 2005) despite considerable public commitment and effort from individual utilities to improve energy efficiency, reduce fossil fuel usage and reduce greenhouse gas emissions.

The importance of climate, energy and water to the past, present and future development of both urban and rural Australia cannot be understated. Human health and well-being, settlement patterns, economic well being and environmental conditions are all strongly influenced by these three factors (Proust et al. 2007). Issues associated with and linkages between climate, energy and water will become more critical in future.

In early 2008 Australia signed the Kyoto Protocol and instigated a new climate change policy. A commitment now exists to introduce a carbon trading scheme by 2010. Consequently Australian planners now face more rigorous energy and greenhouse gas emissions management expectations. Additional pressure will also be exerted on energy and greenhouse gas efficient strategies and technologies as global carbon prices continue to rise. Addressing these implications through policy and practice remains a significant challenge for the sustainable management of urban water in Australia and globally.

2. RESEARCH OBJECTIVES AND FOCUS

The key objectives of this study were to provide:

- Context for current operational energy use by water utilities within the total urban system and compared to the residential energy use for hot water heating;

- Analysis of energy use across the urban water cycle considering how future water management choices may influence energy demand and greenhouse gas emissions; and

- Preliminary analysis of energy-related greenhouse gas emissions from the water sector based on available data.

Energy consumption was evaluated for (1) the centralised system for the provision of urban water services, (2) demand for residential hot water use; and (3) total urban energy use (See Figure 1).
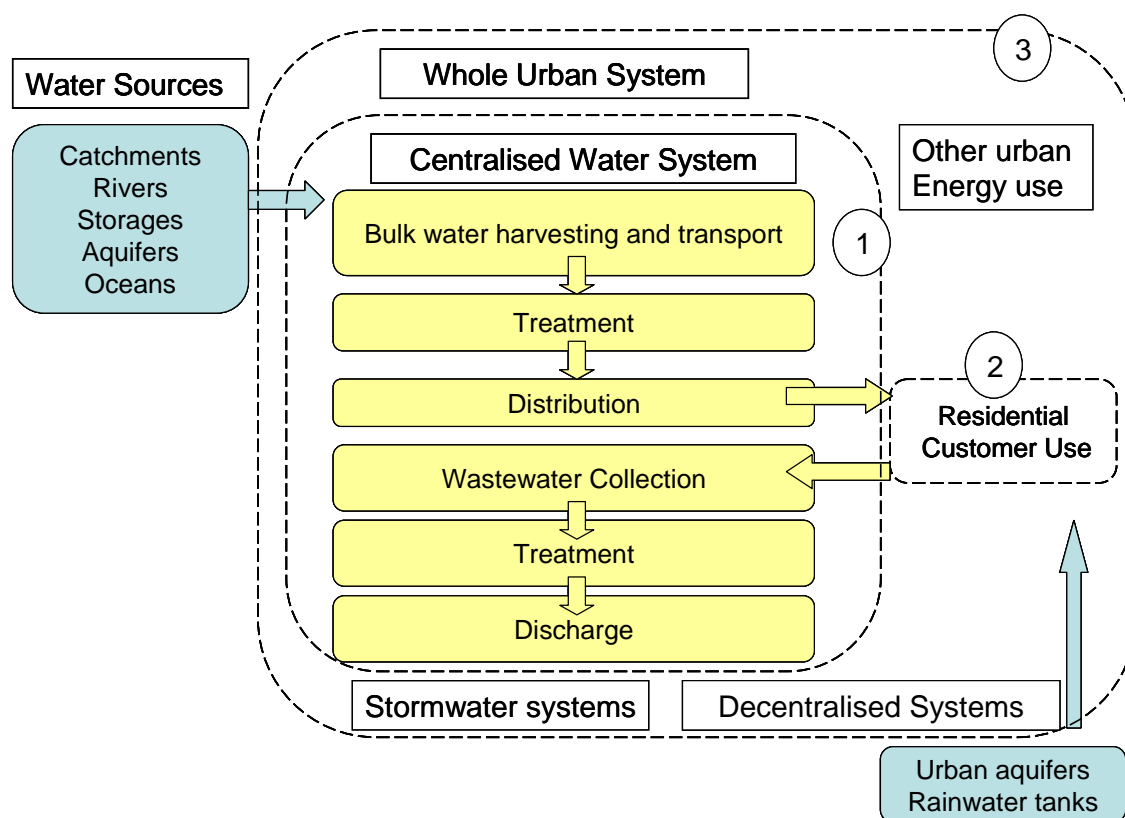
Figure 1   Water cycle and urban system components evaluated for energy use

The methodology for this study included the following work components and was highly reliant on data provided by participating utilities.

2.1   Energy use across the centralised urban water cycle

Centrally-managed water supplies were the focus for this work as they represent the largest volumes of water moved through cities. Detailed data on energy consumption was sourced from water utilities to a consistent pro-forma for the 2006-07 year. Overview information on energy sources, historic

trends of energy and related data were also sought as was a breakdown of greenhouse gas emissions and current and forecast water use and end-use breakdown. In a few cases fugitive greenhouse gas emissions through the water cycle were also provided. These data were augmented with other publicly available data. Further detail on the methodology is presented in Section 3.

Energy use associated with the stormwater system and decentralised supplies were not specifically analysed nor is energy use associated with rainwater tanks and backyard bores. This is because these options currently represent relatively minor components of urban supply at the national level, however they can be important in individual cities. While the current energy use of decentralised systems is estimated to be relatively low (perhaps with the exception of Perth), it is expected to grow as these systems are more widely adopted. Energy use associated with rainwater tanks can be high (Gardner et al. 2006) and is approximately 3,600 MJ/ML (Marsden Jacob & Associates 2007) though this use too is significantly affected by factors such as system design, particularly pumping energy, and the balance of indoor and outdoor use of water. Further analysis of the energy used by decentralised systems is warranted once base data is more available.

2.2   Consumer water-related energy use

Following a literature and data review, this task focussed on estimates of energy demand for residential water heating. Energy for residential water heating was derived by firstly breaking-out total per capita water use to specific end uses (e.g. showers). The volume of hot water required for each end use has been calculated as a percentage of the total. This has been on the basis of figures presented in the literature and the per capita values then scaled up to total volume of residential water requiring heating by the population being served. Lastly, the energy required for residential hot water is estimated using a first principles equation. Further information on the method used to estimate consumer water-related energy use is provided in Section 4.

Accounting for factors such as thermal efficiency of different hot water systems and energy sources were not taken into consideration for this coarse estimate. These estimates were cross checked with other publications of estimated energy use in residential hot water. To illustrate the impact that energy source and Hot Water System (HWS) type has on energy consumption and GHG emissions, national data from the Australian Greenhouse Office is presented along with a household case study of different HWS and demand management strategies.

2.3   Total urban system energy use and urban metabolism

Consideration of total urban systems energy use was undertaken because the project wanted to introduce the concept of urban metabolism into a wider sphere. Urban metabolic analysis requires characterisation of all mass and energy flows into and out of an urban region. While this project focuses on water and the associated energy, it simultaneously considers total energy flows through the cities considered. The urban metabolism model provides a clear and practical pathway to finding sustainable solutions (Newman 1999; Pamminger and Kenway 2008; Sahely et al. 2003).

Published national data on urban systems energy use and energy-related greenhouse gas emissions were compiled to enable comparison with data from the survey and hot water analysis described above. This project derived urban systems energy use by taking pro-rata estimates of State-wide energy use for the cities considered.

2.4   Forecast energy use of alternate water strategies

Future energy needs through the water cycle were estimated for three potential levels of residential water usage assuming a mix of future supplies and energy intensities of each supply as described in Section 6.2.

2.5 Notes on approach

Despite defining "treatment" and "transport" energy (Refer to definitions), separation of available data on a site-by-site basis was not practicable for all utilities and the separation process itself is problematic. Clarifying comments have been made where appropriate or known - however specific comparisons of treatment or pumping within or across utilities need to include consideration of specific local context.

While the report focuses on 2006-07 because of increased data availability for that period, there is significant variability from year to year as local circumstances have influenced energy use, particularly the need to transfer water to supplement low storages.

While the objective of this project was to capture the major flows of energy associated with water, it was not, however, possible to capture all sources largely due to the complexity and, in places, fragmentation of water cycle management. For example in Melbourne and Auckland, where multiple retail water utilities exist, only one was surveyed and taken as a proportional representation of the whole.

Discussion on energy-related greenhouse emissions in this report also do not include offsets or sequestration, therefore greenhouse figures quoted outside this report may be lower due to the affects of considering offsets or sequestration. At this point, fugitive emissions are not consistently measured or reported therefore, due to the uncertainty and knowledge gaps, this report does not provide analysis on fugitives. WSAA however is currently undertaking further research on fugitive emissions to develop better estimation methodologies. This work is considered a high priority as decision-makers rely on greenhouse gas estimates which cannot be derived solely from energy use data.

2.6 Cities evaluated

The project focused on major urban systems in Australia and New Zealand via collaboration with WSAA member organisations in Sydney (Sydney Water and the Sydney Catchment Authority); Melbourne (Melbourne Water and Yarra Valley Water (one of three retail utilities in Melbourne)); Brisbane Water and Gold Coast Water, both in South East Queensland; Perth (Water Corporation of Western Australia); Adelaide (South Australia Water Corporation); and Auckland in New Zealand (Watercare Services Limited and Metrowater Limited (one of five retail utilities)) (Figure 2).

Figure 2   Location of cities examined in the project

3. ENERGY USE BY WATER UTILITIES

In this section data from each city are broken down into energy associated with pumping and treatment for both water supply and wastewater disposal (energy used by utilities). In some cases, more detailed data allows an analysis of the effect of both plant capacity and treatment technology on energy demand and gives some indication of energy requirements of possible future supply schemes. All figures are quoted in gigajoules (1 GJ = 10^9 joules).

A summary of the raw data from each water service provider (water utility) surveyed is provided in Appendix 2. The data is aggregated to "city" level and presented below in Table 1.

Table 1   Energy and Water Use by city 2006-07

	Sydney	Melbourne	Perth	Brisbane	Gold Coast	Adelaide	Auckland
Population served	4,300,000	3,621,000	1,535,108	1,006,000	492,000	1,095,000	1,232,000
Total Water supplied (GL)	507	412	235	113	65	159	136
Residential Water Supplied (GL)	315	257	170	61	40	112	83
Indoor water use %	65	84	53	-		-	-
Wastewater collected (GL)	487	296	119	86	47	89	104
Total energy water supply – pumping (GJ)	1,687,960	125,355	423,000	28,245	39,416	1,041,901	44,460
Total energy water supply – treatment (GJ)	186,009	12,860	409,000	246,337	9,234	55,418	56,749
Total energy wastewater – pumping (GJ)	119,916	459,713	92,800	39,726	50,030	32,064	42,697
Total energy wastewater – treatment (GJ)	698,205	739,243	213,000	138,028	119,389	185,194	273,593
Other Energy Demand (GJ)	250,838	131,728	162,700	49,070	39,461	123,240	23,157
Total energy all demands (GJ)	2,942,929	1,468,900	1,300,500	501,406	257,530	1,390,957	430,504
Greenhouse gas emissions for Energy related sources (k t CO_2-e)[1]	774	302	313	138	75	392	31

Notes: [1]Amounts quoted are Full Fuel Cycle (refer to Definitions and Appendix 1) and are as reported by water utilities surveyed in January 2008; Offsets are not accounted in this row therefore offsets or net emissions reported outside this report may be lower due to the affects of considering offsets or sequestration. Brisbane's population served excludes bulk water supply to surrounding areas; Melbourne wastewater flows only includes flows to Melbourne's two main WWTP (WTP and ETP); Total energy figures for Auckland are derived by multiplying figures reported by retailer by 3 (i.e. Metrowater serves 1/3 of Auckland's population) and then added

to figures reported by bulk supplier (Watercare); Melbourne GHG figures – Yarra Valley Water serves 42% of Melbourne population, figures reported are scaled up by 2.4 to represent all retailers; Auckland greenhouse gas emissions are only for bulk supplier (Watercare) as no figures were available for the retail utility surveyed. Other energy demand includes offices etc. Source: All data is sourced from this survey of utilities or as otherwise noted in Appendix 2.

3.1   City trends and comparisons

This part of the report includes a profile of energy use for each city involved in the study followed by analysis of the commonalities and differences between each city. Comment on the trends in energy consumption is made together with the impacts of environmental and health regulations and scale of operation. Finally, contributions of energy consumption to greenhouse gas emissions and scope for reductions are discussed.

Table 2 provides a comparison of energy intensities for water supply and wastewater disposal between the different cities. It should be noted that this data is for the year 2006-07 only and includes some significant events that distort the numbers for Adelaide and Sydney in particular.

As can be seen, energy intensities for water supply ranged from 6,607 GJ/GL for Adelaide to 335 GJ/GL for Melbourne. This wide disparity can be readily explained by the fact that, because of extreme drought conditions, Adelaide pumped large quantities of water from the Murray River to bolster its reservoir storage volumes. Similarly, Sydney pumped large quantities of water from the Shoalhaven River to meet atypical water shortages. Consequently this significantly boosted its energy consumption to around double. In contrast, the majority of Melbourne's water supply was gravity fed from mountain catchment storages. These figures clearly illustrate the significant energy requirements for lifting water against gravity which is typically required for long distance water transportation. In fact, Adelaide's figure of 6,607 GJ/GL is more than half of the energy intensity of seawater desalination (approximately 12,600 GJ/GL).

For wastewater treatment and disposal, energy intensities ranged from 4,051 GJ/GL for Melbourne to 1,610 GJ/GL for Sydney. These figures illustrate the fact that Sydney discharges most of its wastewater directly to the ocean after primary treatment, while Melbourne transports its secondary and tertiary treated wastewater relatively long distances, which involves considerable elevation, before ocean disposal.

The energy intensity of imported energy (i.e. does not include internally generated energy from biogas) for all services ranges from 8,748 GJ/GL (Adelaide) to 3,165 GJ/GL (Auckland). On a per capita basis, Adelaide at 1,270 MJ/(cap*a) is the most energy intensive supply per capita, while Auckland at 349 MJ/(cap*a) is the least intensive supply.

Table 2   Energy and Water Use Intensity by City (2006-07)

	Sydney	Melbourne	Brisbane	Gold Coast	Perth	Adelaide	Auckland
Energy Intensity Water (GJ/GL)	3,696	335	2,431	748	3,540	6,607	744
Energy Intensity Wastewater (GJ/GL)	1,679	4,051	2,069	3,605	2,570	2,469	3,041
Total water supplied (kL/cap/a)	118	114	112	132	157	145	110
Total water supplied (L/cap/d)	324	312	308	362	419	398	304
Residential water supplied (L/cap/d)[2]	201	195	166	223	303	280	185
Indoor water use (L/cap/d)	130	163	123*	165*	161	207*	
Total energy GJ/GL supply	5,805	3,565	4,440	3,962	5,534	8,748	3,165
Total energy imported (MJ/cap/a)	684	406	498	523	866	349	349

Source: Data from Table 1 are based on data provided by water utilities to a pro-forma designed by CSIRO.
*[2] Residential water use is strongly related to restriction levels and other factors which vary from year to year. Water consumption levels in 2006-07 were 18% lower for Brisbane than 2005-06 and 10% lower for Melbourne. Perth water consumption was approximately 5% higher than the preceding year. Longer-term analysis is necessary to identify trends and underlying causes. *Estimated assuming 74% of water use is for indoor purposes (the average of Sydney and Melbourne).*

3.1.1   Sydney

Sydney Water and the Sydney Catchment Authority jointly manage Sydney's urban water supply system. Sydney's water supply comes mainly from Warragamba Dam and is mostly gravity fed. However in drought periods (e.g. 2006-07) extensive pumping from the Shoalhaven system occurred which sharply lifted Sydney's energy consumption for water supply. Sydney also has 14 water filtration and/or chlorination plants of which four are privately operated. Sydney has 29 Wastewater Treatment Plants with the three major coastal plants processing about 75% of the total volume of wastewater. These plants provide primary treatment, with deep ocean outfall disposal. One of these plants, North Head STP, requires all wastewater to be lifted 50m to the treatment plants, which is on the top of the headland. The ocean outfalls require sufficient pressure to enable dispersal of the effluent. North Head STP accounts for about 15% of the total electricity consumption of Sydney Water Corporation.

In parallel with a number of other Australian cities, Sydney shows a steadily increasing population while the volume of water supplied has declined significantly in direct response to demand management strategies. There are however, inherent physical limits to ongoing reductions in water supply in the face of incessant population growth. Population growth will be the dominant driver of increased future demand for water supplies. The most notable feature of the data is the significant increase in energy for water supply pumping beginning in 2002-03 as a consequence of sourcing water from the Shoalhaven River. For 2006-07, total energy for water supply represents about 70% of total energy consumption, with energy for wastewater treatment making up most of the remainder. Energy requirements for both water treatment and wastewater pumping are both relatively low.

The energy intensity of water supply in Sydney in 2006-07 was around 3,696 GJ/GL, which has increased by 300% since 2000-01 when the energy intensity was 915 GJ/GL. The energy demand for water supply pumping in Sydney has grown consistently over that period as lower than average rainfall has necessitated increased pumping from the Shoalhaven. These figures illustrate that pumping water long distances and against gravity can be very energy intensive.

3.1.2   Melbourne

Melbourne Water provides bulk water and wastewater services for Melbourne. Yarra Valley Water, one of three retail water companies in Melbourne, has been used on a pro rata basis to provide an estimate for the total Melbourne area.

Data for Melbourne from 2000-01 to 2006-07 shows a steady rise in population, while the total volume of water supplied is in steady decline. Demand management and enhanced public awareness of decreasing rainfall patterns, declining inflows into storages and subsequent water restrictions have played a significant role in this reduction. The energy requirement for water supply fluctuates significantly during this period. This is due to changes in the level of pumping from the Yarra River into Sugarloaf Reservoir.

Despite this fluctuation, Melbourne Water's energy use is characterised by a low energy requirement for water supply, with about eight times more energy being used for wastewater disposal (about 0.14 x 10^6 GJ versus 1.2 x 10^6 GJ respectively). This relationship is easily understood as most of Melbourne's water is gravity fed from protected mountain catchments, and only a small percentage is treated while the wastewater is pumped long distances and requires extended levels of treatment.

In 2006-07, the energy intensity of Melbourne's water supply was only 335 GJ/GL, about an order of magnitude less than that for Perth. In contrast, Melbourne used about 4,051 GJ/GL to treat and dispose of its wastewater, although about 40% of this energy was internally generated through biogas production at the wastewater treatment plants.

Electricity was by far the major source of energy, with natural gas also being a significant source at about 10% of electrical energy. However, internal generation of electrical power from biogas (as discussed above) meant that only 60% of Melbourne's electrical power consumption was imported from fossil fuel sources (e.g. coal fired power plants). From a greenhouse gas perspective, this internal power generation has a significant impact, as the imported electrical power comes from the Latrobe Valley power plants which have relatively high greenhouse gas intensity (368 kg CO_2-e/GJ for full fuel cycle).

3.1.3   Perth

Perth has demonstrated a slow but steady increase in both population and volume of water supplied from 2001/02 to 2006-07. This water was supplied with a fairly steady energy intensity of around 2,000 GJ/GL, but with a dramatic jump to 3,540 GJ/GL when the desalination plant was commissioned in 2006. The dominant source of energy for Perth's water system is electricity (1.15 x 10^6 GJ), with 57,200 GJ being generated from biogas produced in wastewater treatment plants.

The additional demand for energy created in 2006-07 for the desalination plant means now that the power requirements for water supply pumping and treatment are two to three times those for wastewater, which can be attributed to the relatively low pumping energies required and relatively small volumes of wastewater flow compared with water supply. Energy intensity for wastewater disposal at 2,570 GJ/GL is significantly lower than that for water supply at 3,540 GJ/GL.

At the moment, electricity consumption dominates the production of greenhouse gases by the Water Corporation and this will continue as the volume of water provided by desalination grows. However, the Water Corporation is working to reduce the level of greenhouse gas reduction through a number of initiatives including; supplying the new Southern Sources Desalination plant with renewable energy (Green Power)(See Figure 5); capturing and using biogas for heating and electricity generation; and focusing on energy efficiency (WSAA Energy & Greenhouse Mitigation Strategies, 2008 pp 27-29).

3.1.4   Brisbane

Brisbane Water's energy use profile has declined despite a slow but steady increase in population of about 1.2%. This is likely due to the declining volume of water supplied from 2004-05 in response to

the severe water restrictions imposed as a result of very low storage levels. Brisbane Water has relatively high energy intensity for water supply at 2,431 GJ/GL, mainly as a result of the need to pump water to the Mt. Crosby and North Pine treatment plants. This energy required to pump water from pumps based at the treatment plants is incorporated with the total energy reported for water treatment. The requirement for tertiary treatment of wastewater before discharge to Moreton Bay is also a significant driver of energy use, resulting in an energy intensity of 2,069 GJ/GL for wastewater disposal and a contribution of about 40% of total energy requirements.

The vast majority of Brisbane Water's energy requirements are supplied by electrical power, with only a relatively small amount of energy (10,000 GJ or 2%) generated from biogas for internal purposes (digester heating). As 98% of energy is generated from coal fired power stations, significant greenhouse gas emissions are incurred.

3.1.5 Gold Coast

Data for the Gold Coast show that energy demands for the Gold Coast has been gradually increasing whereas the volume of water supplied and the associated energy consumption has varied in response to reduced rainfall and subsequent low storage levels. The energy intensity of water supply is fairly low at 748 GJ/GL, reflecting the relatively simple treatment requirements and the gravitational head provided by the main water source (Hinze Dam). The requirement for wastewater treatment to tertiary standards means that wastewater management dominates the total energy requirements, being about 78% of the total. Energy intensity for wastewater management is about 3,605 GJ/GL. Electricity dominates the energy supply picture, providing 87% of total energy requirements and virtually all of this is produced from coal fired power stations.

3.1.6 Adelaide

The population supplied by SA Water and the supply volume have remained fairly steady over the last three years, however the total power requirements for water supply depends significantly on the percentage of supply pumped from the Murray River at Mannum. In 2006-07, the power requirements for pumping jump to an all time high of 995,000 GJ. The reason for this dramatic increase was the pumping of an extra 48 GL of water from the Murray River to provide extra storage during drought conditions. Energy for water supply pumping increased by 117% from 2005-06 to 2006-07. The increased pumping is reflected in the energy intensity of water supply of 6,607 GJ/GL in 2006-07, which is some twenty times the energy required per volume for Melbourne's water supply. This dramatic increase highlights the relatively high energy usage associated with water pumping. Electricity from coal fired plants is the dominant energy source for Adelaide's water system.

Energy consumption for wastewater pumping and treatment in Adelaide was about 20% of that for water supply at around 217,258 GJ per annum. This is largely due to a very low pumping energy requirement of only around 32,000 GJ per annum (note: there is a 20 metre fall between Adelaide city and Bolivar Wastewater Treatment Plant). The other interesting factor is that most of the energy for wastewater treatment is generated in gas turbines fed either by biogas generated in the treatment plant or imported natural gas. This fact means that only about 15% of the energy used in wastewater treatment comes from imported electricity. The energy intensity of wastewater management in Adelaide is around 2,469 GJ/GL. This figure is relatively small compared to other utilities, while the use of biogas and imported natural gas further reduces the greenhouse gas footprint for wastewater management in Adelaide.

3.1.7 Auckland

Data for Auckland includes data supplied by Watercare (the bulk supplier) and Metrowater (one of three retailers in the Auckland region). As Metrowater supplies about 34% of the population of greater Auckland, the data were multiplied by a factor of three before adding to those of the bulk supplier. The data supplied shows a slow but steady growth in both population and volume of water supplied, while energy involved in water supply remains fairly flat. The energy intensity of water supply is fairly low at around 744 GJ/GL, while that for wastewater disposal is significantly greater at 3,041 GJ/GL. This

situation is a reflection of the high energy requirement for tertiary treatment of wastewater, this demand being greater than all other energy demands combined (about 60% of total energy consumption).

Electricity is the dominant source of energy, although significant quantities of natural gas are used for power generation at the wastewater treatment plants. About half of the total electricity consumption of 400,000 GJ is generated internally from biogas. As a consequence, the greenhouse gas footprint for urban water supplies to Auckland is likely to be relatively small, as the imported electricity is largely generated from clean sources such as hydro, geothermal and natural gas.

3.2 Energy use commonalities and differences

The energy consumption data discussed above for individual cities highlights the fact that local circumstances and regulations have a significant impact on the energy use profile. Figure 3 provides an aggregation of data for each city broken up into the individual demands for energy. In some cities such as Adelaide, Perth and Sydney, water supply required the most energy input for 2006-07. In other cities such as Melbourne and the Gold Coast, wastewater disposal uses larger amounts of energy. Also, cities such as Adelaide and Perth use significantly more energy per customer than other cities like Melbourne and Auckland. As outlined in the previous section, local conditions contribute significantly to these outcomes. Also, as outlined earlier, care is needed in interpretation of the data. For example in some systems, large amounts of energy is used to pump raw and treated water to elevated treatment plants (e.g. Mt Crosby in Brisbane) and this is classed as treatment energy because of the location of the plant.
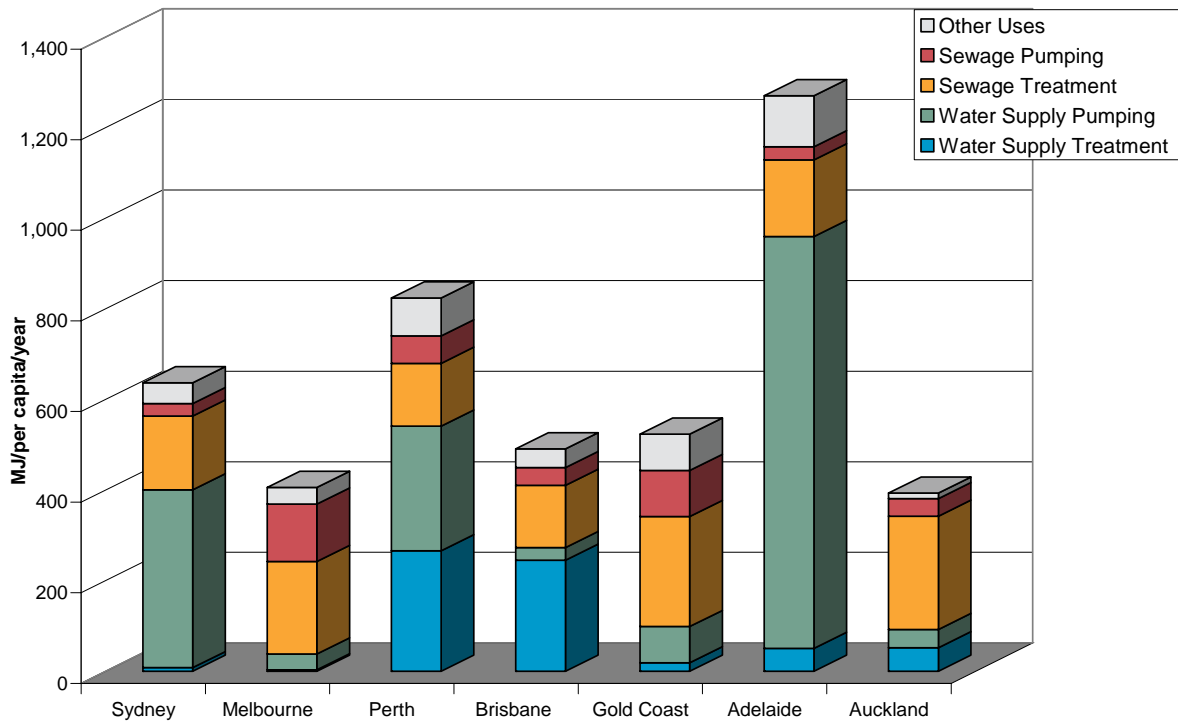
Figure 3   Energy breakdown for water and wastewater services (2006-07)

Figure 4 provides a more detailed profile of the different energy demands for each city. Key observations here include the high energy requirement for pumping for both Adelaide and Sydney's water supply and the relatively high energy for tertiary wastewater treatment in Auckland and the Gold Coast. At the other end of the scale, Adelaide has particularly low energy requirements for wastewater pumping, while Sydney and Melbourne use very little energy for water treatment.

It needs to be emphasised that these figures relate to the financial year 2006-07 and therefore reflect the local circumstances of that time period, such as extraordinary pumping of water to ensure reliability of supply (i.e. for Adelaide and Sydney). However a very clear message emerges from the 2006-07 data, and that is pumping water is extremely energy intensive.
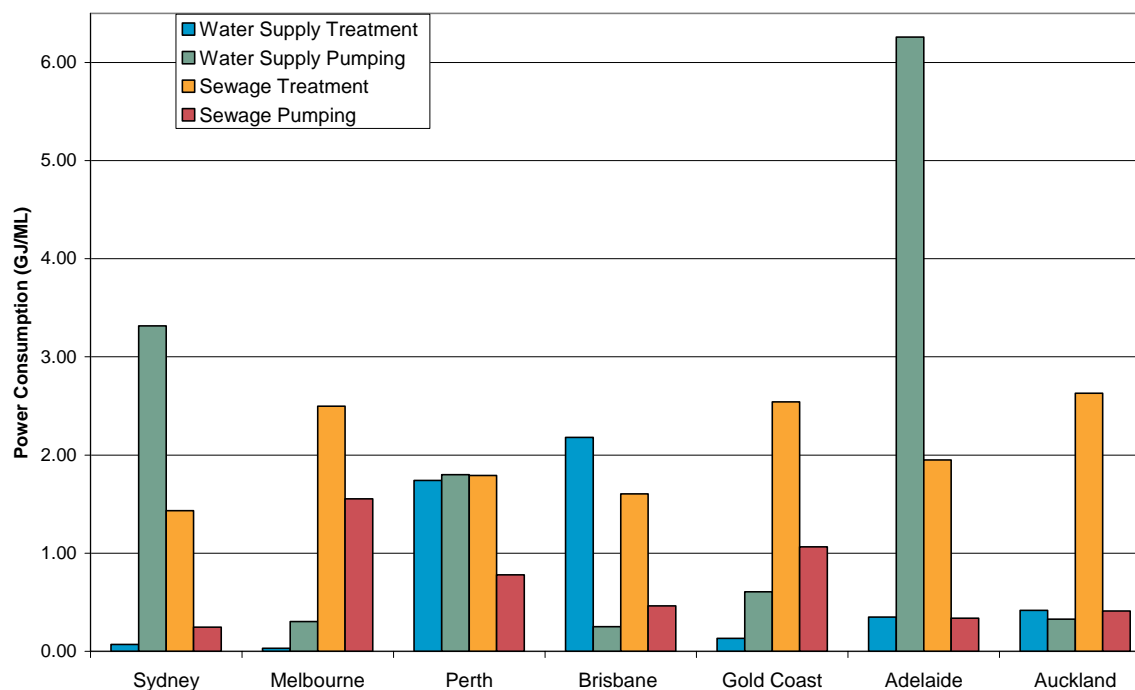
Figure 4   Energy intensity of water and wastewater services by city (2006-07)

Notes: Total energy use is shown and includes imported and self-generated energy sources (i.e. they are energy used, not net energy use); Wastewater energy consumption intensities are cited per volume of wastewater treated; Approximately 70% of the water supply treatment energy for Brisbane is for on-site pumping.

3.2.1   Wastewater treatment energy requirements

Table 3 provides an analysis of the energy intensity of the various levels of wastewater treatment and gives some indication as to why Auckland and Gold Coast are relatively energy intensive. On average, energy intensity doubles between primary and secondary treatment and then doubles again between secondary and tertiary treatment. For tertiary treatment, there are a wide range of energy intensities, reflecting the particular technologies involved (e.g. extended aeration to membrane bioreactors). There did not appear to be any economy of scale for tertiary treatment with plants ranging from 1.6 ML/d to 48 ML/d capacity having much the same energy intensity. However, there were some small plants (<1 ML/d) with energy intensities as high as 16 GJ/ML. Further analysis of the implication of scale on treatment efficiencies appears warranted.

Table 3   Energy intensity of wastewater treatment (2006-07)

	Range GJ/ML	Average GJ/ML
Primary	0.36 – 1.34	0.8
Secondary	0.93 – 2.96	1.65
Tertiary	1.41 – 39.6	3.25

Source: Data provided largely by Sydney Water and Brisbane Water. Refer to definitions for description of Primary, Secondary and Tertiary treatment.

3.3   Greenhouse gas emissions

Energy related greenhouse emissions are the predominant source of GHG emissions from water utilities, however, non-energy related sources, often referred to as "fugitive emissions" (e.g. methane and nitrous oxide from wastewater treatment) also contribute a significant amount. Due to the uncertainty and knowledge gaps in calculating fugitive emissions, it was considered beyond the scope of this report to provide analysis on fugitives. WSAA however is currently undertaking further research on fugitive emissions to develop better estimation methodologies.

Standard electricity, imported from the grid, is the dominant energy source for most water utilities with Sydney Water and Gold Coast reliant on electricity for over 90% of their power needs (Figure 5). When the GHG intensity of each of the energy sources used by utilities is considered, electrical energy dominates all utilities (for which the data is available) with Sydney, Melbourne, Perth, Brisbane and Gold Coast demonstrating over 90% of their reported energy-related emissions from standard electricity (Figure 6).

3.4   Comments and scope for reductions

Many utilities are currently taking steps to reduce energy use and greenhouse gas emissions. Measures being adopted include (WSAA 2007):

- Avoiding energy use where alternative options exists and achieve the same service outcome (e.g. through system design and operation);

- Improving energy efficiency measures (e.g. installation of variable speed rather than fixed speed pumps and use of pumping strategies to minimise energy and use off-peak power);

- Utilising wastes (e.g. biogas, bisolids, heat, pressure and flow (e.g. for mini-hydro)) to generate renewable energy;

- Sequestering carbon (e.g. through woodlots and tree farm establishment); and purchasing offsets (e.g. through green energy purchase options).

Other strategies are typically necessary for fugitive emissions although these options are not addressed in this report which focuses on energy use. It should be noted however, that the use of biogas as an energy source has a double benefit in that it reduces fugitive methane emissions from entering the atmosphere as well as reduces the use of standard imported electricity.

Electricity is the current dominant source of energy in the provision of urban water sources in Australia. As much of this power is sourced from coal-fired power stations (apart from Auckland), its contributions to greenhouse gas emissions becomes even more accentuated as other sources such as natural gas and diesel produce much less greenhouse gas per megajoule of energy produced. Consequently, efforts to minimise greenhouse gas emissions from water service operations need to focus attention on the use of imported electricity.

Biogas is generated in wastewater treatment for the production of either process heat or electricity which can be used in pumping or treating water or wastewater. Melbourne is a good example of the beneficial use of biogas where about 40% of their energy for wastewater treatment and disposal is generated by this means. In Adelaide biogas is used with imported natural gas to drive combined cycle gas turbines for electric power production.

Water supply systems can also be designed to generate electricity through hydro-electric schemes. The use of hydro-electricity can offset pumping energy that may be used to pump water by recovering energy when water is flowing downhill. Wolff *et al.* (2004) details a number of North American water pumping systems that are net producers of energy. Sydney Water is currently implementing a project where hydro-electric generators will capture energy from wastewater flow down a dropshaft at the North Head Wastewater Treatment Plant.

Pumping water long distances and/or to overcome gravity is clearly an energy intensive process and one which cannot be offset through any associated biogas production which is the case for wastewater treatment. Consequently, long distance water transportation needs to be carefully examined for its energy implications, particularly in comparison to sourcing recycled water or desalinated water much closer to its point of use.

Tertiary treatment of wastewater also creates higher energy demand than secondary or primary treatment. The main reason for requiring tertiary treatment is to remove nutrients, such as nitrogen which may cause eutrophication and water quality degradation in receiving waters. In many cases, such regulations are necessary and the high quality water produced may then be available for various water reuse applications.
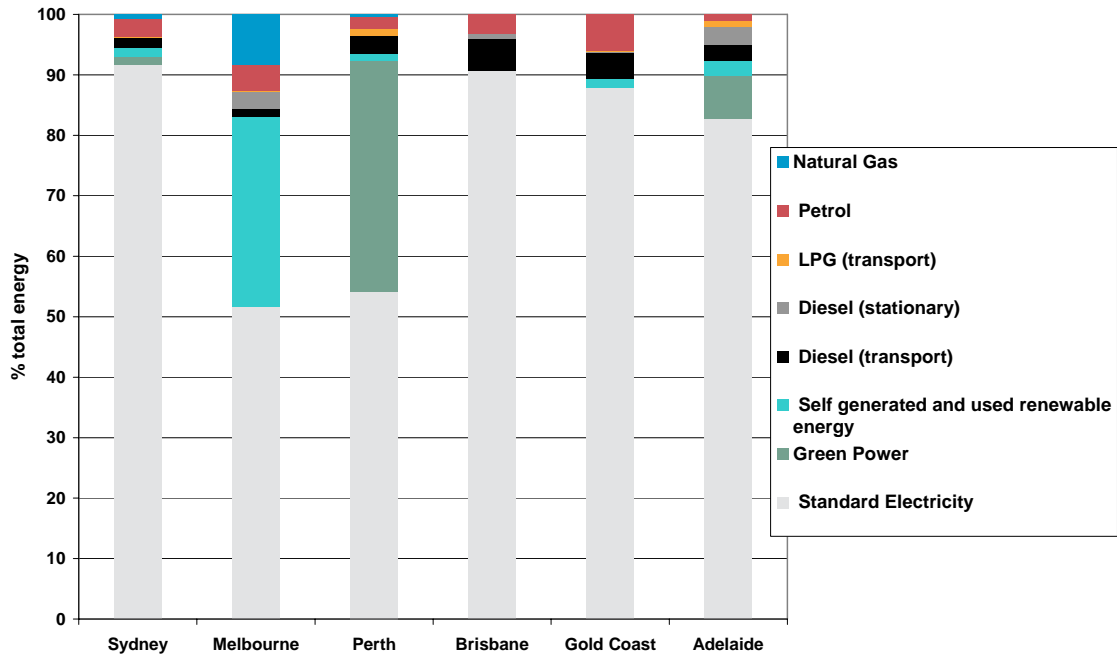
Figure 5   Energy use by water utilities by source (2006-07)
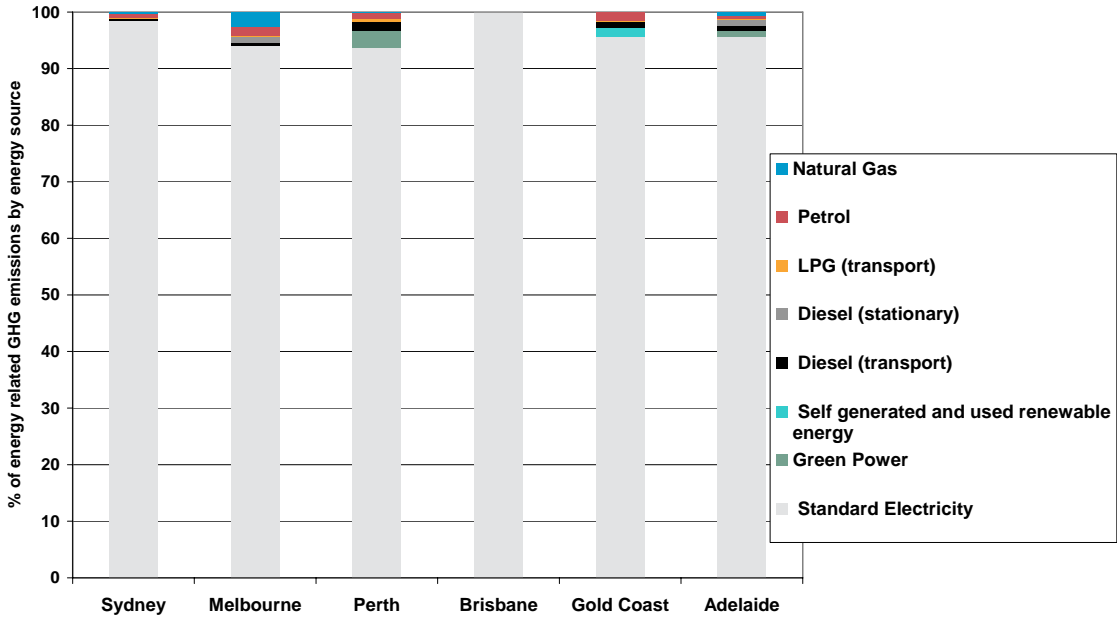
Figure 6   Energy related GHG from utilities by energy source (2006-07)

Notes: Where transport fuels have been reported in a volume (e.g. kL) they have been converted to energy on basis of AGO workbook (AGO 2006); For Sydney the results aggregate data for Sydney Catchment Authority and Sydney Water; In Melbourne the data includes YVW retailer scaled up by 2.4 to represent all retailers and whole of city scale plus Melbourne Water data.

While current urban water systems have significant infrastructure which combines black water with grey water in the sewers, around 90% of the nitrogen and about 60% of the phosphorus is contained in the black water. Separation of black water in new urban developments could not only open up possibilities for energy and nutrient recovery, but also greatly reduce the need for tertiary treatment based on nitrogen removal. With the recent doubling in price of nitrogenous fertilisers worldwide due to price increases for natural gas, such initiatives could provide a path to more sustainable urban water systems[1] This approach could also facilitate simpler and safer water recycling operations, as the source for the recycled water would not be heavily contaminated with human waste.

Managing greenhouse gas emissions is a more complex issue than simply reducing energy use, however there is a need for improved data on fugitive emissions and scope boundary to provide cost-effective drivers for reduction. WSAA is progressing research in the area of fugitive emissions to provide better estimation methodologies.

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[1] Natural gas is the key source of energy in the Haber-Bosch process for nitrogen fixation in the manufacture of nitrogenous fertilisers.

4. WATER USE AND ASSOCIATED ENERGY USE

This section focuses on the energy and associated greenhouse gas emissions that can be directly attributed to end-use of water supplied to a customer. Estimates of residential hot water are made and residential energy use information sourced from the literature.

Residential hot water was a priority for this study as it represents a significant portion of the total energy use associated with water end-use and has a relatively good quality data set when compared with other uses such as industrial use. Figure 7 depicts that water heating is responsible for 25% of residential energy demand and 27% GHG emissions in Australian households. In New Zealand household energy use by end-use shows that a similar proportion of energy is going into water heating (around 29%) as Australian households (Branz 2003) with space heating and air-conditioning (22%), lighting (11%) and refrigeration being the next major users.

Residential Energy Use by End Use

Residential GHG Emissions by End Use

Legend: ■ Space Conditioning ■ Water Heating ■ Cooking ■ Appliances □ Lighting
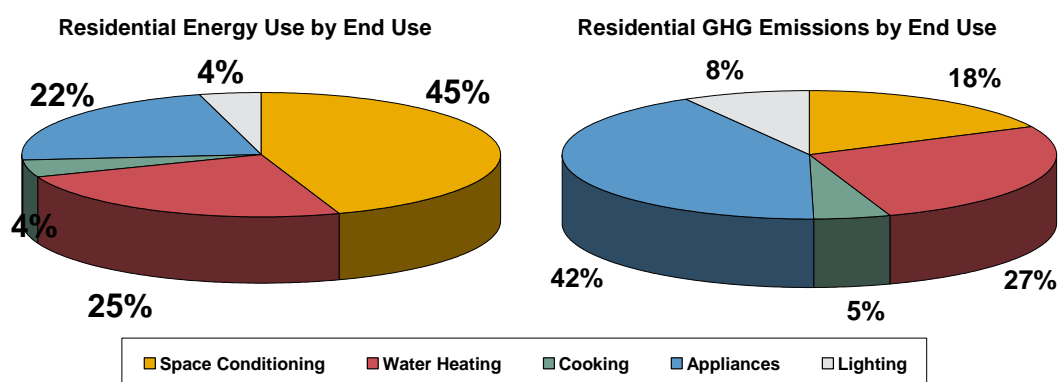
Figure 7   Residential energy demand and GHG emissions end use allocation

Source: AGO, 2002.

4.1   Introduction

Households use significant amounts of energy to heat water. Wolff et al. (2004) make the point that the greatest reductions in energy consumption in the urban water cycle can be achieved through increased water efficiency by end-users. This is due in part because a reduction in urban water demand will reduce the "upstream" energy required in sourcing, treating and pumping water to end-user and also reduce energy required "downstream" to treat and discharge wastewater. However, the greatest impact on energy demand is through reducing demand for water in energy intensive end-uses, in particular those requiring water heating. Flower et al (2007) found that residential end-use of water can be responsible for substantially more greenhouse gas emissions than all upstream and downstream operations. This demonstrates the benefits of addressing end-use water efficiency in strategies aimed at reducing energy consumption and greenhouse gas emissions in the urban water cycle.
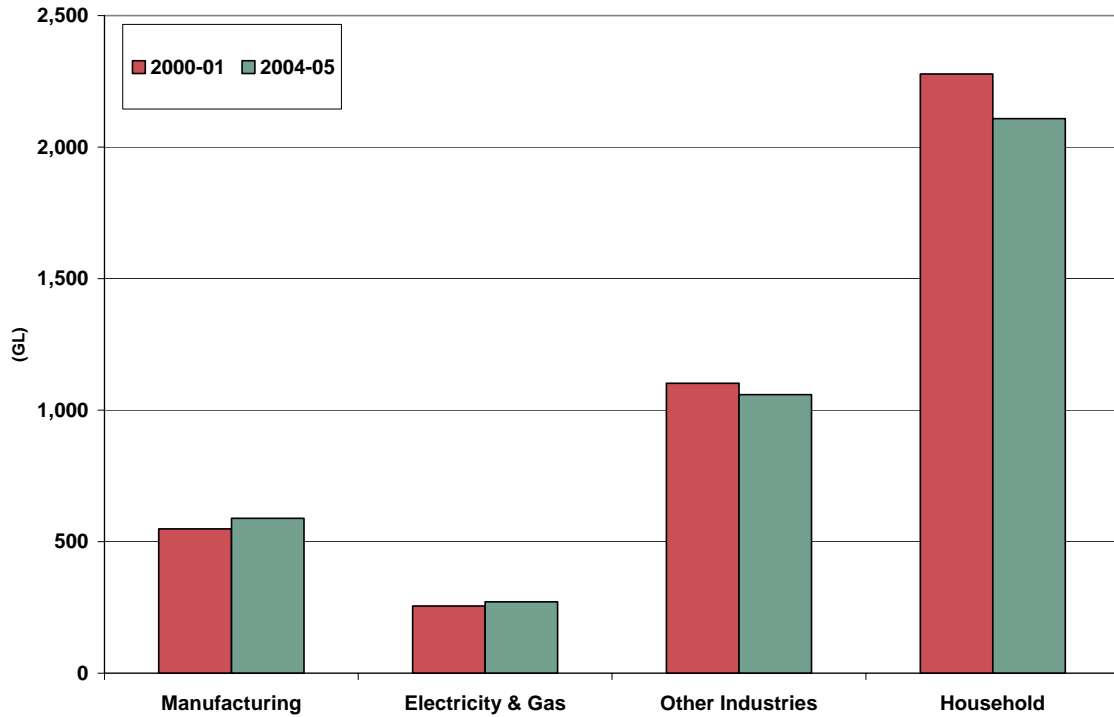
Figure 8 depicts the urban water use by sector for the financial years 2000-01 and 2004-05. This shows that residential water use has the greatest demand for water services accounting for 52% of total demand. The greatest growth in this period occurred in the manufacturing sector that increased consumption by 7%, while households reduced overall demand by 7%. This reduction in household demand can be attributed to demand management strategies and water restrictions that have been implemented in response to an extended period of below average rainfall.
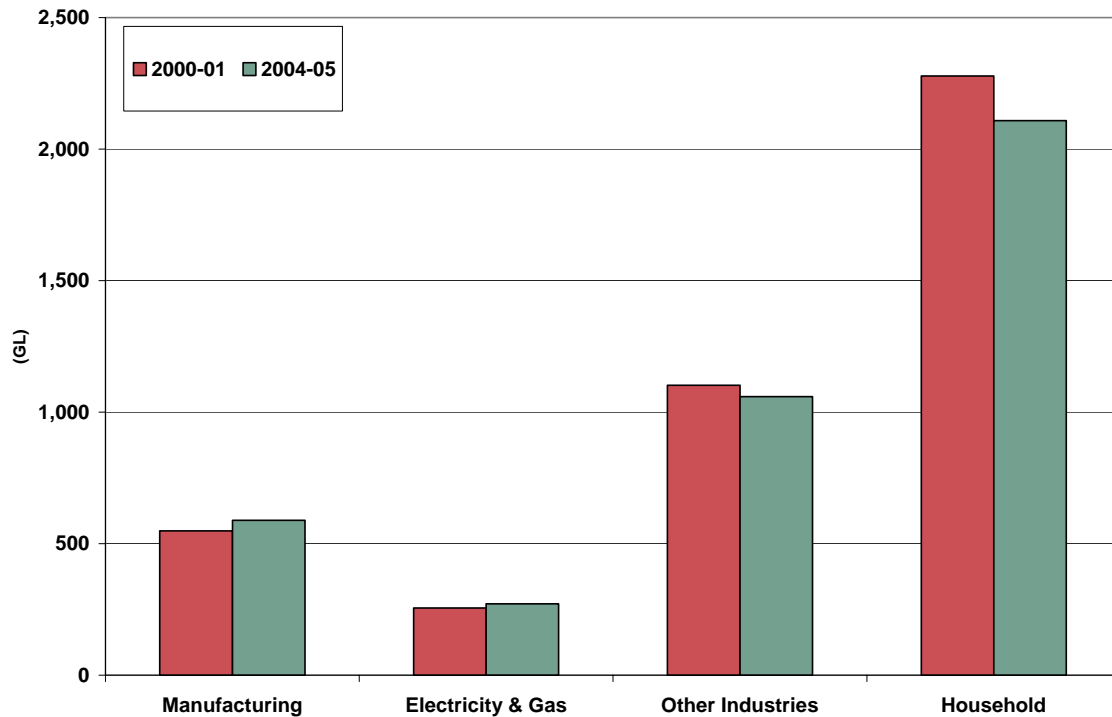
Figure 8   Australian urban water use by sector (Source: ABS, 2006)

The total amount of water demand by households varies significantly between cities, which is mostly a factor of outdoor water demand. The pattern of outdoor water demand is influenced by climate, soil type and garden size.

In 2006-07 Brisbane had the lowest per capita demand for water, which is due in part to ongoing water restrictions in South East Queensland (Table 2). Perth had the highest level consumption followed by Adelaide. The higher levels of consumption in Perth can be attributed to the higher levels of garden irrigation, due to the sandy soils requiring frequent irrigation as well as Perth not being subject to as severe water restrictions compared to other capital cities. Historically, outdoor water use has been a large consumer of water in Australian households as in 2000-01 households in Brisbane, Adelaide and Perth all reported using more than 50% of total water for outdoor purposes while in Sydney (25%) and Melbourne (35%) a smaller proportion is used outdoor purposes (ABS, 2005). The impact of extended water restrictions is likely to have changed this breakdown with residential restrictions focussed primarily on outdoor uses. An end-use study of households situated on New Zealand's Kapiti Coast revealed that only 8.3% of total household demand is for outdoor use (Heinrich, 2007).

4.2   Residential and hot water energy use

4.2.1   Background

Energy consumption in the residential sector has grown linearly and nearly doubled since 1973-74. Energy for water heating is a significant component of residential use however, energy is also used for filtering, pumping and heating swimming pools and spas (around 3.3% of household energy use (George Wilkenfeld and Associates 2004)), followed by dishwashers and washing machines. This section focuses on energy associated with residential Hot Water Services (HWS) which can be defined as units that heat water and deliver to point of demand.

Factors influencing household hot water demand are the flow rate, occupancy rate, household composition, installed appliances and the temperature of cold water. Family income and cultural

background also influence hot water consumption. Factors influencing household energy expenditure related to water heating are fuel type, inflow temperature, set temperature, water heater type, appliance types and efficiency ratings, and any water or heat losses (Aguilar *et al.*, 2005).

The energy consumption of the hot water system is not just related to the volume of hot water used, but also is influenced by the physical properties of the system such as volume of heated water stored, amount of insulation and thermostat temperature. To accurately model hot water energy demand there is a need to understand both demand for hot water and the physical properties of the system. Good sources of data are critical to produce accurate models (Pollard *et al.*, 2002).

4.2.2   Estimated Energy Demand for Residential Water Heating

Estimates of energy demand for residential water heating have been made in this study to determine relative impacts of different end-use demand scenarios on total energy for the urban water cycle. Limitations of data and the focus of this report meant that highly accurate estimates of energy for residential water heating were beyond the scope of this study. The estimates are based on a number of assumptions and are only intended as an approximation; therefore, actual values should be treated with a high degree of uncertainty. The following assumptions have been made in estimating residential hot water energy demand:

- The per capita residential water demand has been derived from data supplied by utilities where the total volume of residential water supplied has been divided by population served.

- The proportion of water going to indoor use is based on residential end use breakdowns provided by utilities. Where this information was not available the proportion was derived from a mean of Sydney and Melbourne (Perth was excluded as considered not representative of split between indoor and outdoor demand due to high irrigation requirements).

- The proportion of indoor residential consumption going to each end use was based on figures from George Wilkenfield and Associates (GW&A 2004; See Figure 9).

- The volume of hot water required for each end use was also based on figures from GW&A (2004). See Figure 10 for an example of proportion of end use demand requiring water heating. This figure indicates that for a household using approximately 300 L/day approximately 90 L is used for hot water. Of the hot water approximately 46 L is used in the shower or bath and a further 20 L from taps.
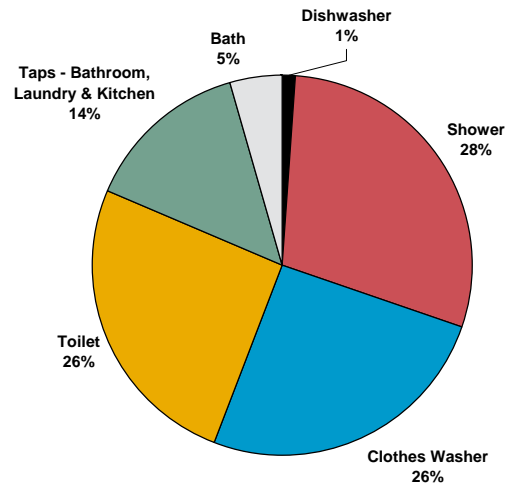
Figure 9   **Indoor household water demand by end-use for Australia**

(Source: GWA, 2004)
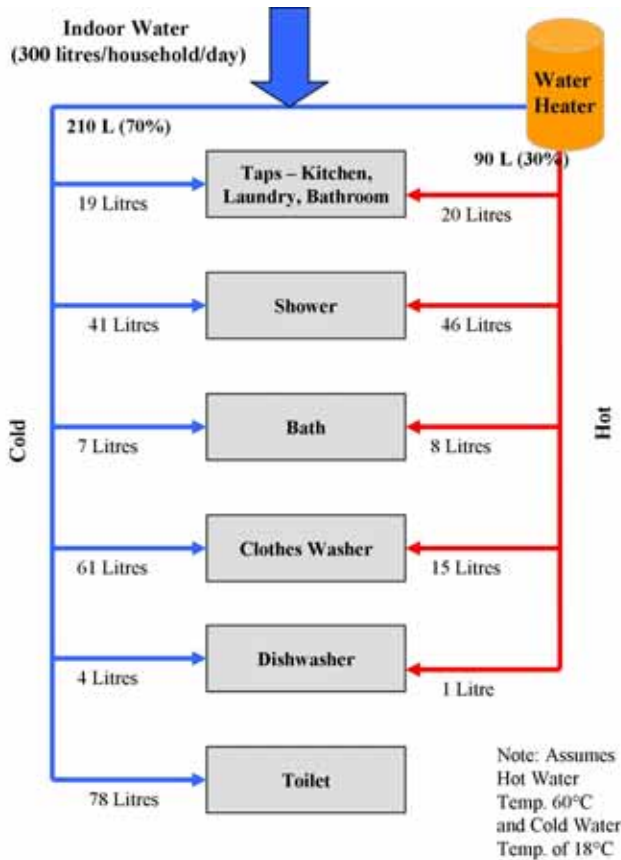
Figure 10   Sample breakdown of water end-uses - hot and cold

(Source: Adapted from GW&A, 2004; Note 300 L per household per day indoor use is approximately equivalent to 160 L/cap/day residential use for indoor and outdoor purposes.

The energy required to heat the volume of hot water required is based on a first principles equation $E = CM\Delta T$ (based on http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/spht.html). In this equation, E is the energy required to heat the water to the required temperature; C is the specific heat for water (amount of heat per unit of mass required to raise temperature one degree Celsius); M is the volume of water to be heated; T is the increase in temperature required. A temperature end point of 60 °C and start point of 18 °C was assumed for all cities. This cold water temperature was based on the average monthly cold water temperature for Climate Zone 3 (Sydney and Brisbane) specified in AS/NZS 4234-2007 (Standards Australia, 2007).

The per capita values are scaled on the basis of population served. The estimate of energy use for Residential hot water (Table 4) does not incorporate fuel sources for water heating or thermal efficiency of different hot water systems.

Table 4   Residential hot water - volume and energy (2006-07)

City	Residential water supplied (GL/a)	Total Indoor (GL/a)	Volume of Residential. Hot Water (GL/a)	Energy for Residential Hot Water (PJ/a)
Sydney	315	205	82	14
Melbourne	257	216	86	15
Brisbane	61	45	18	3
Gold Coast	40	30	12	2
Perth	170	87	35	6
Adelaide	112	83	34	6
TOTAL	**955**	**665**	**267**	**46**

To enable comparison of these estimates with other available figures the Australian Standard 4552-2005 (Gas Fired Water Heaters for Hot Water Supply and/or Central Heating) was used. This standard suggests a daily standard load of 37.7 MJ per household, which is used in determining the energy rating of water heating appliances. This figure is assumed to apply more at the higher end of household water use. Applying the assumed thermal load of 37.7 MJ/day the residential energy demand was calculated to enable comparison with figures estimated for this report. Calculating energy for residential water heating based on AS 4552-2005 resulted in values that were 25% higher than those presented in this report when averaged across cities. While both these figures are inherently uncertain due to the difficulty in accurately modelling energy to a household end-use, it however, provides an idea of the energy going into residential water heating and indicates figures for this project underestimate energy use.

The fact that thermal efficiency was not considered in the estimates of water heating energy also influences the under estimation of figures presented in this report. In many cases the hot water systems themselves are quite efficient, but in the case of electric systems only 33% of the energy reaches the point of use due to losses during electricity generation and transmission. The impact of demand management strategies, such as low flow shower roses, on energy demand for water heating are explored in subsequent sections.

4.2.3   Influence of Energy Source for Water Heating on GHG Emissions

Figure 11 shows the primary energy source for water heating in Australian Cities, which shows that in Melbourne the majority of households (77%) use gas for water heating while Sydney 57% of households are reliant upon electricity. A survey of New Zealand households on energy end-use revealed that 79% of households surveyed had an electric storage HWS and only 8% used gas storage HWS with a further 5% households served by gas instantaneous HWS (BRANZ, 2003). The influence of energy source for water heating on GHG emissions is significant. For example while electric hot water systems account for nearly 50% of the energy used for water heating, due to inefficiencies they account for around 80% of the CO_2-e. In contrast gas storage systems account for around 35% of national energy use for residential water heating and around 12% of the greenhouse gas emissions (GW&A 2002). In Australia electricity accounts for around 48% of the energy going into water, but it accounts for nearly 80% of the GHG emission related to residential water heating. This is due the fact that in Australia electricity is a relatively 'dirty' energy source in terms of GHG emissions due to the reliance of brown/black coal to fuel power stations.
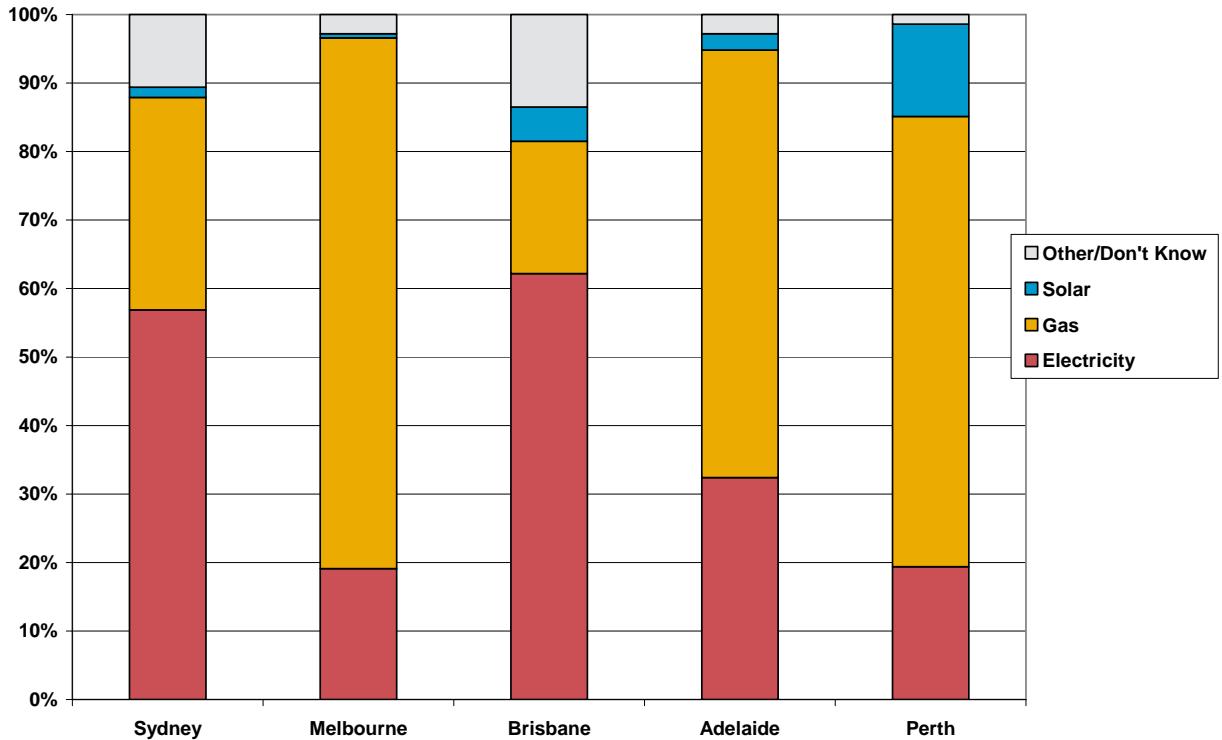
Figure 11   Primary energy source for water heating in Australian cities % households

(Source: ABS, 2005), Note: estimates of greenhouse gas emissions from water heating within each State could not be sourced.

The type of hot water system and energy source has a substantial impact on the total energy required to deliver hot water and the associated GHG emissions. Figure 12 depicts results of scenarios modelled by Sustainability Victoria (pers. comm.) that demonstrates the relative impact of different types of HWS and energy sources on GHG emissions and energy demand for an "average" household (HH). The following assumptions were used:

- 3 person household

- Average daily hot water use of 178 litres (65 kL/yr/HH)

- Base annual energy load for household water heating of 12,213 MJ/yr (based on equation detailed in Section 4.2.2)

- GHG coefficients were applied on basis of National Greenhouse Accounts Factors (2008)

This shows that solar systems have the lowest demand for imported energy from gas and electricity. The gas boosted solar unit is the most efficient in terms of GHG emissions. Table 5 shows the estimated annual GHG emissions for different HWS for Melbourne by household size, which reinforces gas boosted solar systems are the most efficient in terms of GHG emissions. On average 20% of the energy used is consumed by standing losses, which explains why for many of the systems the actual energy consumed is more than the energy required to heat the water. Off-peak electricity HWS has slightly higher energy consumption and GHG emissions than peak electricity HWS due to the higher standing losses in the off-peak system, which heats the water overnight.
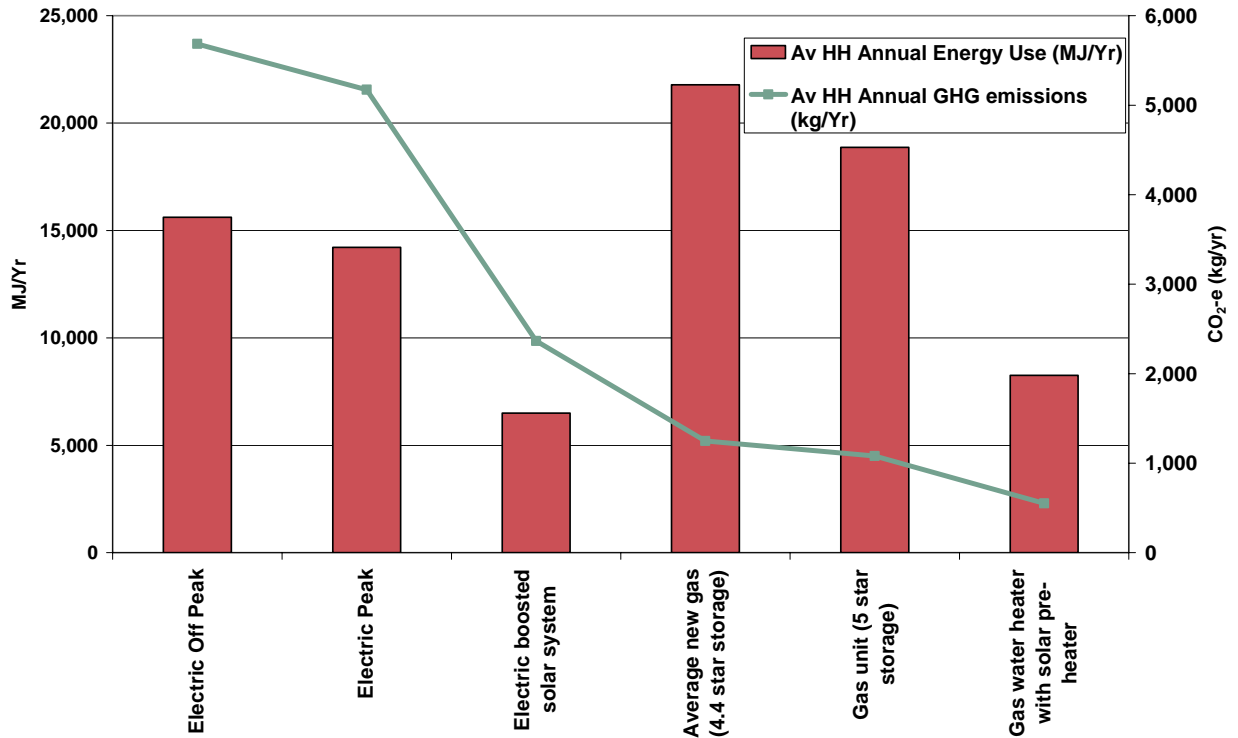
Figure 12   HWS impact on energy demand and GHG for average Victorian household

Source: Data from Sustainability Victoria May 2008

Table 5   GHG emissions from various hot water systems (Melbourne)

	Tonnes of greenhouse gas emissions per year		
	Household size (number of people)		
	Small (1-2 people)	**Medium (3-4 people)**	**Large (5+ people)**
Electric Storage (off-peak)	3.6	5.8	7.4
Electric Storage	3.4	5.8	8.3
Electric Heat Pump Storage	0.9	1.5	2.2
Solar (Flat-plate) Electric Boost	1.4	3.3	4.7
Solar (Flat-plate) Gas Boost	0.1	0.4	0.8
Gas 3 Star Storage	1.2	1.7	2.2
Gas 5 Star Storage	0.9	1.4	1.9
Gas 5 Star Instantaneous	0.6	1.1	1.7

Source: Energy Strategies (2007)

4.2.4   Demand Management Strategies

The purpose of this section is to explore the impact of two demand management strategies on residential water demand for hot water and associated energy and GHG emissions, which considers HWS type. All information presented in this section is based on information supplied by Sustainability Victoria.

The first strategy simulates the impact of shifting from a normal shower rose to a WELS 3 star rated low-flow shower rose for both a high and low water usage scenario. Characteristics common to both scenarios were:

- 3 person household

- 0.9 average daily showers per person over the year

- Hot water temperature of 60°C and cold water temperature of 15°C

- Shower temperature of 40°C (56% hot water)

The WELS 3 Star rose is assumed to have an average flow rate of 8.1 Litres/minute. Table 6 characterises two scenarios - high water usage household and low water usage household. This table also shows the relative impacts on the hot water demand and associated energy for a shift to a 3 Star rated low flow shower rose. Figure 13 demonstrates the impact of this shift in terms of GHG emissions avoided by HWS, which considers thermal efficiency of different systems, which shows that the biggest savings are associated with electric systems due to relatively high emissions associated with coal-fired electricity.

Table 6   **Range of possible energy savings through use of a WELS three star shower rose.**

	Low water usage scenario	High water usage scenario
Shower flow rate (L/min)	12	15
Average shower time (min)	4	7
Current shower water use (L/yr)	47,304	103,478
Current hot water use	26,280	57,487
Current energy demand for shower water heating (MJ/yr)	4,950	10,829

Shower water use with 3 star shower rose (L/yr)	31,930	55,878
Water saving with 3 star shower rose (L/yr)	15,374	47,600
Hot water savings (L/yr)	8,541	26,444
New energy demand for shower water heating with 3 star shower rose(MJ/yr)	3,342	5,848
Energy savings (MJ/yr)[1]	**1,609**	**4,981**

[1] *Not considering HWS thermal efficiency; Data Source: Sustainability Victoria May 2008*
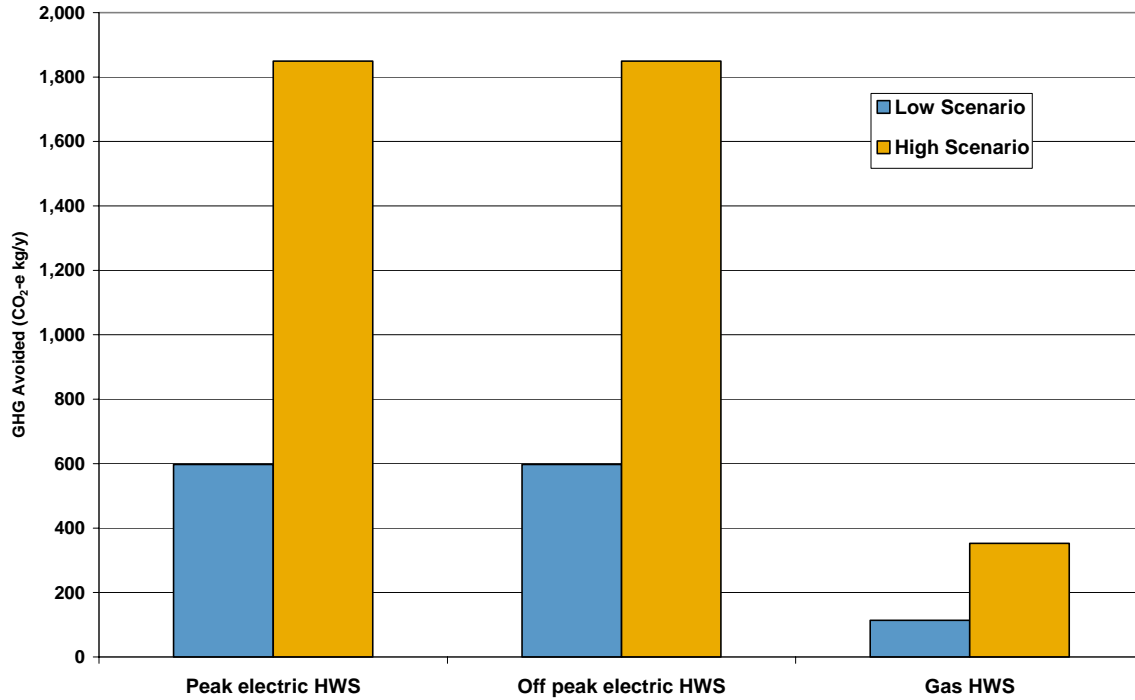
Figure 13   **Range of GHG savings achieved per household through installation of a 3 Star shower rose**

Data Source: Sustainability Victoria (May 2008)

The second demand management strategy explored is a shift to a 4 star front loading washing machine from a WELS 2.37 Star rated top loading new machine currently on the market assuming 250 washes a year; 50% of washing on cold wash cycle and 44.5 kWh/yr electrical consumptions of pumps and motors. Under these assumptions for the modelled household, 10 KL of water would be saved a year if shifting to a 4 Star front loader from 2.37 Star clothes washer. Table 7 compares the assumed performance for the two clothes washers.

Table 7   **Comparison of 2.37 star top loading clothes washer with 4 star front loader**

	Average new top loading clothes washer (6.5 kg, 2.37 star rating)	Front loading clothes washer (6.5 kg, 4 star rating)
Water consumption (Litres/cycle)	102	62
Comparative energy consumption (kWh/yr)	474	220
Estimated water heating energy (kWh/yr)	409	155

Figure 14 illustrates the potential energy saved and GHG emissions avoided in shifting from an average new top loading clothes washer to efficient (4 Star) front loader
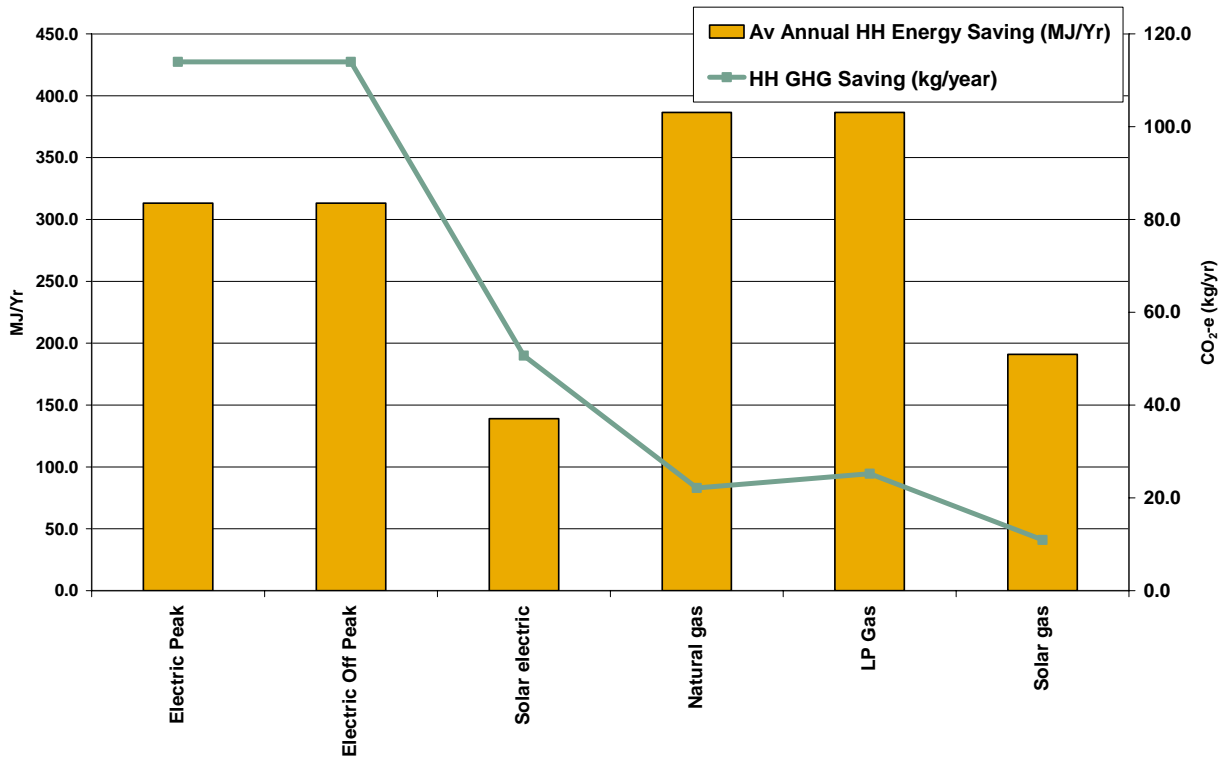
Figure 14   **Energy and GHG savings from shifting from 2.37 star to 4 star washing machine**

Data Source: Sustainability Victoria (May 2008)

4.3   Industrial and other uses of water

There is a paucity of detailed data available on energy associated with water use by industry partly due to the diversity of processes, water use and heating options in place in the commercial, industrial and manufacturing sectors. Australia's National Greenhouse Gas Inventory - 1990, 1995 and 1999, End Use Allocation of Emissions" (George Wilkenfield and Associates 1999) shows that in the industrial sector water heating for amenity (97,000 t $CO_{2\text{-e}}$) is a relatively minor contributor of GHG while industrial boilers (18,538,000 t $CO_{2\text{-e}}$) is a major contributor of GHG and comparable to residential hot water energy use nationally (18,815 t CO_2.e).

Significant new data would be necessary to better estimate energy use associated with non-residential end-use. These data sets would need to include improved attribution of energy use to water end use, and process within industry. It is possible some process data from Life Cycle Analysis of different industry types as well as industry water and efficiency audit data could support such analysis.

5. URBAN SYSTEMS

This section considers the total energy use and greenhouse gas emissions of the overall urban systems that are being served by the various water utilities covered in this report. Additional information is included in Appendix 3.

5.1 Energy Use

Population growth and increasing standard of living is driving the growth of energy consumption in Australia. According to estimates from Australian Bureau of Agricultural and Resource Economics (ABARE, 2006) in the medium term (from 2004 to 2010), Australia's energy consumption is projected to grow by 2.0 percent a year, from 5,593 PJ in 2004 to 6,311 PJ in 2010.

Historical trends in energy consumption for key sectors in Australia show total energy consumption has grown steadily over the period from 1973 to 2006 (Figure 15). Electricity generation, transport and manufacturing are the most energy intensive sectors. The residential and commercial sectors accounted for 10% of total energy consumption in 2005-06, however both these sectors are major consumers in terms of indirect energy consumption. This is demonstrated by the fact that the residential and commercial sectors used 52% of (335.5 PJ) of electricity generated in 2001. Residential energy consumption has nearly doubled since 1973-74.
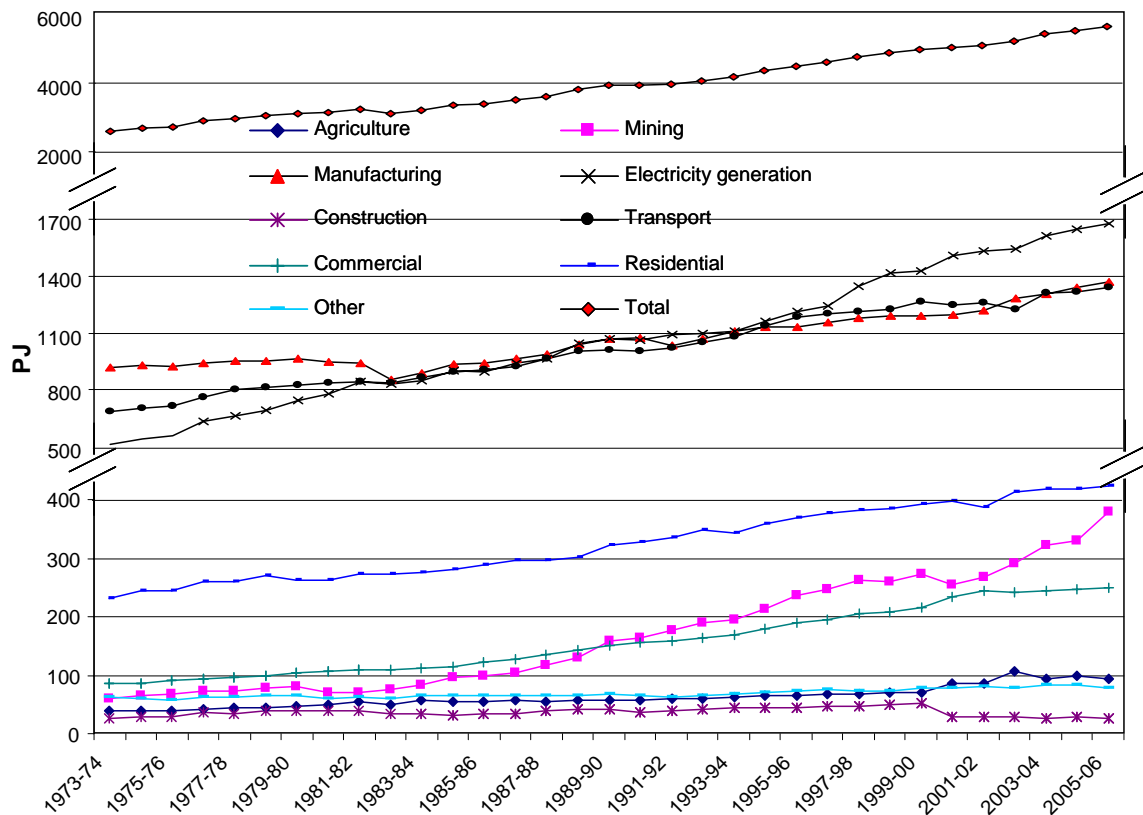
Figure 15   Energy consumption in Australia by sector (ABARE, 2007)

Total energy consumption comprises all energy consumption for water, wastewater, drainage including agriculture, mining, manufacturing & construction, transport, commercial & services (which was classified into Australian and New Zealand Standard Industry Classification (ANZSIC) 6700 storage industries).

Figure 16 shows the total energy consumption for the cities considered in this project, noting that this is a pro-rata estimate of total State energy use attributed to the city shown. Using pro-rata estimates are approximations of "urban systems energy use". However utilising such an approach does assume that individuals in each city do have influence over energy consumption in the rest of the State. For example consumption of materials or energy in a city may influence the amount of mining or agricultural product production required in the State to support that consumption. Alternatively products (e.g. manufactured goods and foods) can be imported from other countries however that typically simply shifts the consumption of water and energy off-shore.
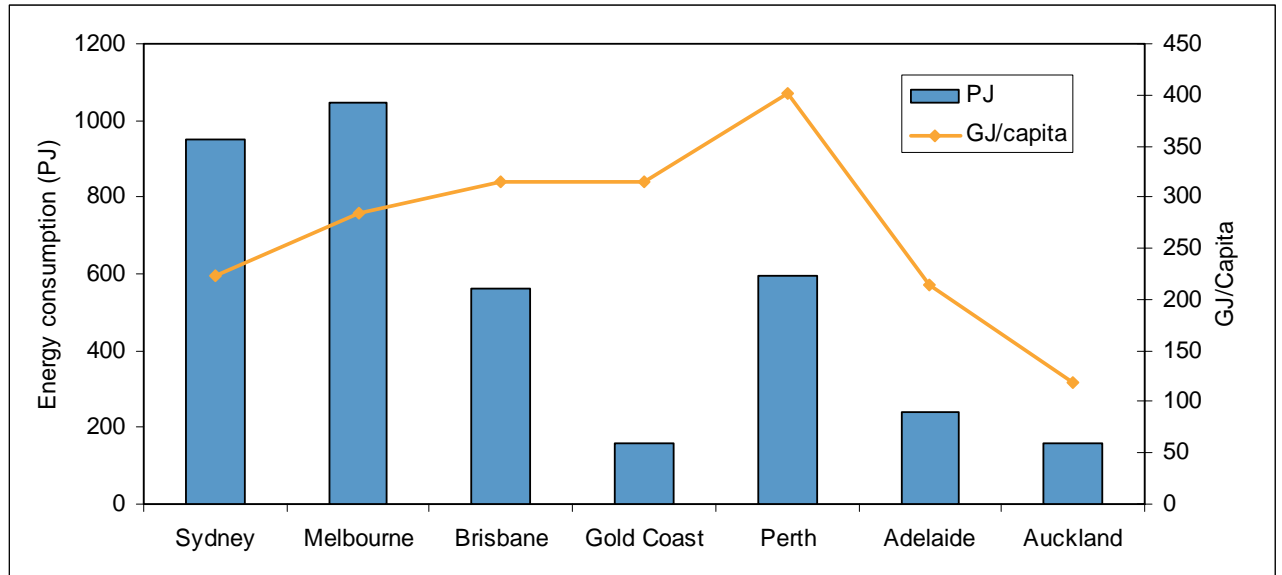
Figure 16   Total energy consumption by city and demand per capita (2006-07)

Perth has the highest per-capita demand for energy (around 400 GJ/capita) however this may be skewed by high energy use outside the Perth area (e.g. mining areas). Auckland uses around one quarter of the energy use of Perth and between one third and one-half the per-capita usage of most Australian cities. This may be attributable to its greater density of development. Sydney and Melbourne have a high total demand for energy because of their population size.

5.2   Greenhouse gas emissions

Data from ABARE's Australian Energy Consumption database indicates that the cities studied in this report emit around 90 Gt (nine thousand million tonnes, for Sydney and Melbourne) through to approximately 12 Gt for Auckland. Electricity use (around 50% of total emissions) and petroleum products (around 40%) comprise the majority of greenhouse gas emissions (Figure 17   ). When compared to these numbers the energy related greenhouse gas emission associated with water services provision (generally less than 1,000,000 t CO_2-e per city) are relatively insignificant.
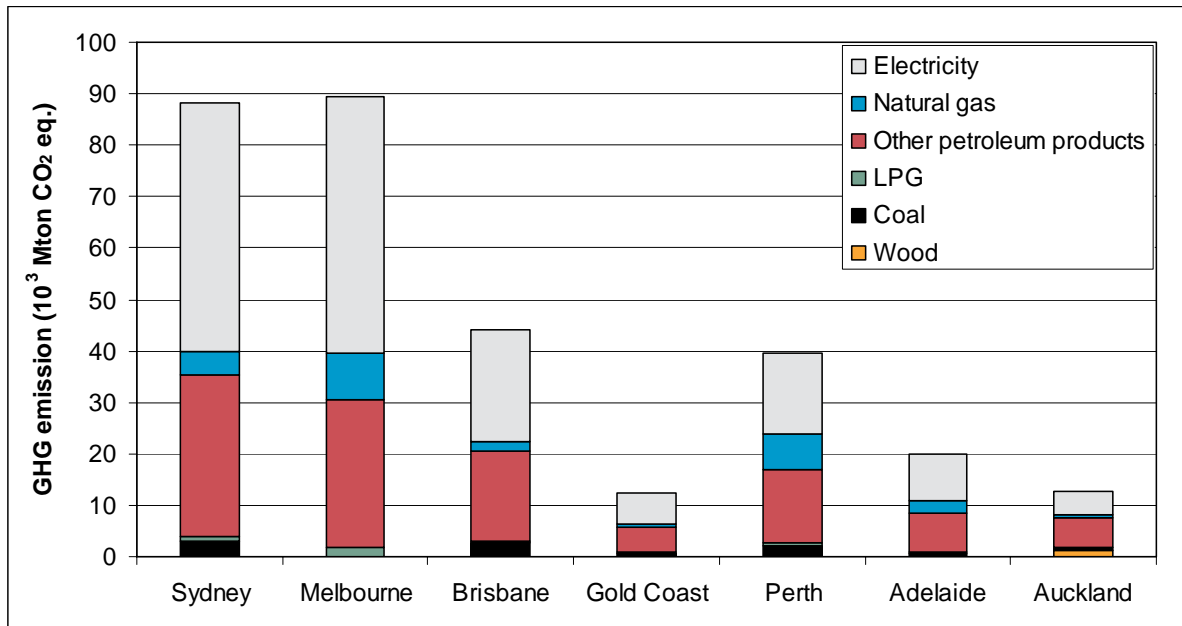
Figure 17 **GHG emissions by final energy consumption for cities (based on 2005)**

6. ENERGY USE BASE CASE AND PROJECTIONS

6.1 Energy use base case

Comparison of the energy used by utilities (W), residential water heating (R) and total urban system (T), (W, R and T in Table 8   ), identifies:

- That energy use by water utilities in 2006-07 comprised 0.1-0.3% of total urban systems with a national average of 0.2%;

- That residential hot water uses at least 0.5% of total urban systems energy use in Brisbane and at least 1.8% in Sydney;

- That the ratio of energy use for residential hot water to energy used by water utilities ranges from 4.7 (Adelaide) to 11.2 (for Melbourne). The higher this ratio the greater the energy-related benefits would exist from focussing on managing indoor hot water demand compared with managing water utility energy use. (Note this is distinct from potential greenhouse gas benefits which require consideration of the efficiency of the water heating appliance and the energy source for that heating).

Table 8   2006-07 energy use for utilities, residential hot water, and total urban system

City	Energy (PJ)			Energy (MJ/capita)			Energy (% of total urban system)		
	Water Utility (W)	Res Hot Water (R)	Urban system (T)	Water Utility (WSAA pop.)	Res Hot water	Urban system (ABS pop.)	Water utility =W/T	Res hot water =R/T	Ratio R/W
Sydney	2.7	14.0	949	626	3,256	223,493	0.3%	1.5%	5.2
Melbourne	1.3	15.0	1045	369	4,144	283,781	0.1%	1.4%	11.2
Brisbane	0.5	3.0	561	450	2,982	314,320	0.1%	0.5%	6.6
Gold Coast	0.2	2.0	157	442	4,065	314,324	0.1%	1.3%	9.2
Perth	1.1	6.0	597	741	3,909	401,716	0.2%	1.0%	5.3
Adelaide	1.3	6.0	242	1157	5,479	213,648	0.5%	2.5%	4.7
TOTAL	**7.1**	**46.00**	**3552**	**590**	**3,818**	**276,727**	**0.2%**	**1.3%**	**6.5**

Note – Total urban system (T) is a per-capita estimate of energy use by the State in which the capital is located. MJ/Capita and % or total urban system figures are weighted averages.

The relatively low percentage of energy use by water utilities compared to energy use in residential water heating (over 5 fold less) indicates that a 20% saving in residential end-use of hot water, for example through demand management or altered consumer behaviour, has the potential to more than offset current energy use by water utilities.

This ratio surprises many and some recent authors (Beal et al. 2008) have noted much lower ratios (e.g. approx 2:1 at Silva Park in Brisbane). However the Silva Park development utilised decentralised water supply options (rainwater tanks, greywater reuse) which required more energy than conventional systems.

The water end-use, hot water and total urban systems analysis identified issues around reporting boundaries for some cities. For example population data for Brisbane Water (1,006,000), and to a lesser extent Adelaide (1,095,000) reported by water utilities (Table 1), were inconsistent with ABS data (1,786,079 and 1,134,579 for Brisbane and Adelaide respectively). This variation is probably associated with using different boundaries within which to characterise the population. This variability was accounted for by using WSAA population data for per-capita energy use for water utilities and hot water use; and using ABS population data for deriving per-capita urban systems energy use.

Substantial variation in the residential indoor end-use of water is evident. Local characteristics (e.g. urban density), climatic variations and the level of water restrictions are contributing factors to these differences.

6.2   Future Projections of energy use

A number of 'what if' projections were considered to understand the upper and lower bounds of future energy use for water and wastewater flows and domestic water heating of an aggregated demand and supply for the urban centres of Sydney, Melbourne, Brisbane, Gold Coast, Perth and Adelaide. The projections aim to provide insight into the main influences on energy use in the water sector and the most effective areas to target for management. However, the emphasis of the aggregate demand and supply and the energy requirements will vary between each urban centre as illustrated by Figures 3 and 4.

The interaction between energy and water is considered in the residential sector. The projection to 2030 captures a number of replacement cycles for hot water systems and presents the opportunity to consider the effect of a different mix of systems. Current practice for the use of gas and solar water heaters in Melbourne and Perth were applied to Australia as a whole.

6.3   Population, Water Demand, Water Supply and Wastewater flows

The collective Australian population serviced by the utilities in 2030 is estimated to be 15.8 million. This is comprised of populations of 5.59 million in Sydney, 4.57 million in Melbourne, 1.5 million in Brisbane, 0.8 million at the Gold Coast, 2.1 million in Perth and 1.2 million in Adelaide (WSAA 2005).

Residential water demand in 2030 was derived by assuming total water use at three levels of per-capita residential consumption: 150 L/(cap*d), 225 L/(cap*d) and 300 L/(cap*d). The consumption levels were chosen to be indicative of current use given data provided by water utilities surveyed. The three residential water demands reflect upper, middle and the lower range of current practice. The use of lower water demand carries with it many social assumptions. The lower water demand (150 L/(cap*d)) is based upon current practice in South East Queensland and other regions facing water restrictions and may not be socially acceptable (or maintained) over the long term. However, it does provide a lower limit for current practice with a caveat that further investigation is required to justify it as a realistic scenario.

Total water use was estimated by increasing residential use proportionally with the current split of residential to total water use (60% residential to 40% non-residential). Wastewater flows were estimated assuming indoor water use comprises 60% of total and also assuming all indoor water use translates to residential wastewater flows. This represents the national average of translation of residential use to wastewater flows however some cities (notably Sydney) have wastewater flows closer to 85% of total (residential and non-residential) water use. Under these assumptions future additional water demands for the six Australian cities studied in this report ranged from 1,388 GL/annum (for 300 L/(cap*d)) through to negligible additional demand (at 150 L/(cap*d)).

Table 9   Water flows at three levels of residential water consumption in 2030

Residential Demand	Total Residential Water Supplied	Total Residential and Commercial Water Supplied	Current water supply capacity	Additional water supply required	Indoor Water Use	Current waste water collected (residential and commercial)	Additional wastewater collected
L/cap/day	GL/year	GL/year	GL/year	GL/year	GL/year	GL/year	GL/year
300	1734	2890	1502	1388	1040	901	833

Energy Use in the Provision and Consumption of Urban Water
in Australia and New Zealand, June 2008

| 225 | 1300 | 2167 | 1502 | 665 | 780 | 901 | 399 |
| 150 | 867 | 1445 | 1502 | -57 | 520 | 901 | -34 |

To meet the predicted future water demand, two water supply source mixes were considered. The first is based on existing strategies to meet future demand. However, future supply options have changed considerably in the past five years. For example, since 2005 when WSAA published 'Testing the Waters' there has been considerable change in strategies for water supply with planning for substantial new desalination plants and increased wastewater reuse and treatment of some wastewaters to potable standards. The first supply mix was based on current national strategies (Qld Government 2006; Water Corporation 2005; WSAA 2005) and assumed new supplies in a ratio of 40% desalination; 40% reuse and 20% new surface water sources. The second supply mix was based on the presumption that 100% new water would be sourced from desalination – an extreme case which perhaps sets an upper bound for energy demand excluding long-distance water transfer proposals (refer Table 11).

6.3.1 Energy Intensities for Water and Wastewater Treatment and Pumping

Future energy use to 2030 assumed that existing sources yielded water at similar energy requirements to those measured for 2006-07. The energy intensity of new future supplies was estimated using the energy intensities shown in Table 10. It also needs to be noted that energy projections are very sensitive to the technologies used. Upper and lower estimates for energy intensities for technologies such as desalination and wastewater reuse are provided where possible. However, it must be noted that energy intensities for these technologies have changed dramatically over the past decade and are very dependent on factors such as input water quality and the type of process.

Table 10   Assumptions used in forecasting energy use in 2030

	Lower Energy Intensity	Upper Energy Intensity	Energy Intensity Used for Projections
	GJ/ML	GJ/ML	GJ/ML
Water Treatment and Pumping			
Conventional water treatment plant	0.36	1.8	1.08
Conventional water pumping	0.25	6.26	1.96
Reverse osmosis on treated wastewater for reuse	3.6	5.4	4.5
Reverse osmosis on sea water	12.6	14.4	13.5
Pumping energy for reuse	3.6	7.2	5.4
Pumping energy for desal	3.6	7.2	5.4
Waste water Treatment and Pumping			
Primary wastewater treatment plant	0.5	1.0	0.8
Secondary wastewater treatment plant	1.0	2.0	1.65
Tertiary wastewater treatment plant	2.0	5.0	3.25
Conventional wastewater pumping	0.25	1.55	0.74

It was assumed that the proportion of primary, secondary and tertiary waste water treatment would follow current practice, which was based upon WSAA (2008) *National Performance Report 2006-2007 urban water utilities*. This gave 20% primary, 25% secondary and 55% tertiary wastewater treatment based upon the total volume treated for all utilities in the National Performance Report. Although secondary and tertiary treatment may increase in many areas it was assumed to be partly balanced by large centres such as Sydney which will continue to use primary treatment and deep water ocean outfalls.

The energy intensity for 'Reverse Osmosis on treated wastewater for reuse' does not include the energy for tertiary wastewater treatment. It was assumed that the volume of available tertiary treated

wastewater (55% of all wastewater flows) would be sufficient to supply the 40% of new water supply required for reuse. This assumption does not evaluate the capacity for various urban centres to supply the required amount of tertiary treated wastewater for reuse. For example, Sydney Water uses tertiary treatment for only 22% of its wastewater (WSAA 2008).

Pumping energy for water and wastewater was calculated as a weighted average using the population served by utilities. Pumping energy, water and wastewater volumes and population collected from utilities was used (as summarised in Table 1). The weighted average captures current pumping energy for city populations and geography. Although applicable at a national level, there is a wide range of pumping energy in particular regions of Australia and may change over time with the growth and spread of cities. Pumping energy for desalination and reuse was considered separately.

6.3.2   Energy Projections

The following tables provide a summary of the energy projections.

Table 11   Estimated additional energy needs for various water supply options to 2030

Residential water use (L/cap/d)	Conceptual sources for providing additional supply (GL)			Estimated additional energy requirements in 2030 (PJ/a)				
	Desalination	Reuse	Surface sources	Water treatment	Water pumping	Wastewater treatment	Wastewater pumping	Total (PJ)
300	555	555	278	10	6.5	2.0	0.6	19
	1388	-	-	19	7.5	2.0	0.6	29
225	266	266	133	4.9	3.1	0.9	0.3	9
	665	-	-	9.0	3.6	0.9	0.3	14

Notes: The volume of additional water required and the volumes from desalination, reuse and new sources for the three consumption levels are shown in Table 9; Wastewater treatment may include some wastewater pumping energy requirements.

Future estimates for energy use of total urban systems were derived as a linear projection based on population growth and ABARE data. The results are presented in Table 12, which also includes ratios of hot water energy to urban water energy (R/W) for the different scenarios, as well as the increase in energy efficiency of hot water production required (MJ/capita) to completely offset the increase in energy consumption resulting from the increased levels of supply.

Table 12   Estimated energy use for supply, hot water and urban total in 2030

Residential water consumption and additional water source	Energy (PJ)			Energy (MJ/capita)			Energy (% of total urban system)		
	Water Utility (W)	Res Hot Water (R)	Urban system (T)	Water Utility	Res Hot water	Urban system	Water utility =W/T	Res hot water =R/T	Ratio R/W
300 L/p/d-mix	26	80	5002	1658	5063	316582	0.5%	1.6%	3.1
300 L/p/d-desal	36	80	5002	2291	5063	316582	0.7%	1.6%	2.2
225 L/p/d-mix	16	68	5002	1032	4304	316582	0.3%	1.4%	4.2
225 L/p/d-desal	21	68	5002	1323	4304	316582	0.4%	1.4%	3.3
150 L/d	7	52	5002	443	3291	316582	0.1%	1.0%	7.4

Note: For all scenarios and per-capita figures a total population of 15.8 million for all case study cities was applied and the existing 7 PJ energy use was added to estimated additional energy needs shown in Table 11. Estimates for hot water energy demand are based on the methodology outlined in Section 4.2.2, with the following additional assumptions; for residential use of 300 L/(cap*d), 225 L/(cap*d) and 150 L/(cap*d) respectively 65%, 75% and 85% of water demand is used for indoor uses. The amount of water going to each end use decreases proportionally with the total demand. This assumes that the 150 L/(cap*d) residential use will have a high penetration of highly efficient appliances. Total urban systems energy use in 2030 is based on forecasts outlined in Table 17.

This analysis indicates that:

- If 100% of new water supplies to 2030 were sourced from desalination (the extreme case) and residential water consumption is 300 L/cap/d total energy use by water utilities would increase to 36 PJ from current use of around 7 (approximately a 500% increase). This would represent approximately 0.7 % of the energy use of the total urban system in 2030.

- If a mix of water sources were provided to meet demand of 300 L/cap/d, total energy use by water utilities would increase to 26 PJ and represent 0.5% of the total urban system in 2030.

- If water consumption is constrained to 225 L/capita/d, energy use for water provision increases to 21 and 16 PJ/a respectively if provided (1) entirely by desalination or (2) by a mix of desalination, reuse and surface sources.

- If water consumption were constrained to 150 L/cap/d energy use by water utilities would remain approximately the same as 2006-2007 and there would be a minor increase (approximately 6 PJ/a) in energy use for residential water heating.

- An improvement in hot water savings of around 28 PJ is realised from high demand management scenario (150 L/(cap*d)) compared to the 300 L/(cap*d) scenario.

These results are consistent with more detailed modelling of Melbourne through to 2045 (Kenway et al. 2008; Kenway et al. 2008 (approved for publication)). Many assumptions have had to be made to make these estimates and it is stressed that local conditions in each system will dictate actual energy requirements and the viability of any particular solution. Importantly too, if residential water consumption can be constrained to 150 L/cap/d and still provide for the services that the community expect, then minimal additional energy would be required for provision of water and wastewater services. A significant policy imperative deriving from this analysis is that focusing efforts on energy efficient hot water production has significantly greater scope for environmental benefits than can be derived from focusing on urban water systems energy in isolation.

The analysis has not considered solar hot water systems due to data limitations, however future work should consider the potential for solar hot water systems to reduce the GHG emissions associated with residential hot water use.

7. EMBODIED ENERGY AND OTHER ISSUES

This report has focussed on operational energy (energy used each year to provide water) as opposed to embodied energy or energy used over the life-cycle of water assets and chemicals used in various processes such as chlorine. The focus on operational energy was made because operational energy is likely to outweigh embodied energy in urban water services provision. For example, Flower reviewed available papers having undertaken life-cycle analysis of urban water systems and found consistently the relative insignificance of greenhouse gas emissions with the pre- and post-operational stages of infrastructure associated with urban water (Flower et al. 2007a; Flower et al. 2007b). This trend, if true, is quite different to the pattern for buildings. For example Tucker (2002) estimated that the annualised embodied energy use in constructing a house (over its 60 year life-cycle) was overtaken by cumulative annual "operational" energy use after 18 years. It is suspected that the relative significance of operational and embodied energy is system-specific (Kenway et al. 2007) and that the influence of future trends including new water sources requires additional system-specific analysis and improved life-cycle data.

7.1 Embodied energy

Embodied energy is defined as: "the quantity of energy required by all of the activities associated with a production process, including the relative proportions consumed in all activities upstream to the acquisition of natural resources and the share of energy used in making equipment and in other supporting functions i.e. direct energy plus indirect energy" (Treloar, 1994). Embodied energy is important to consider in a holistic analysis of energy consumption in the urban water cycle. Consideration of the amount of energy embodied in materials is becoming increasingly important due to the focus on reducing the use of non-renewable energy sources (such as coal) that are associated with increasing levels of greenhouse gases in the atmosphere and is predicted to result in anthropogenic changes to the global climate. In order to reduce greenhouse gas emissions there is the need for more comprehensive analysis of energy consumption in the built environment, including embodied energy (Randolph et al., 2007).

The purpose of an embodied energy analysis is to quantify the amount of energy used to manufacture a material or product. In the case of pipes for water and wastewater services this involves the assessment of the overall expenditure of energy required to extract the raw material, manufacture products and maintain the pipe material being assessed. A secondary aim is to establish the embodied energy required to install and operate the pipe over the whole life cycle. An important consideration in terms of embodied energy over the total life cycle of the pipe is the expected service life of an asset.

The embodied energy value for a particular material is known as the embodied energy coefficient and is usually expressed in terms of energy per material mass. Greenhouse gas emissions associated with the manufacture of this product can be estimated; however the energy source for the manufacturing process is required for this.

Troy *et al.* (2003) found that embodied energy consumption is more significant than first thought when they undertook an estimate of embodied and operational energy consumption for Adelaide using input-output tables. Table 13 presents the annual energy consumption and corresponding CO_2 residential emissions in Adelaide City in 2001. This enables the relative importance of the components of embodied energy consumption and CO_2 emissions to be presented. This analysis demonstrated that the water and wastewater system were responsible for approximately 6% of the total annualised *embodied* energy and associated greenhouse gas emissions in the residential environment (Note this includes more factors than operational energy).

Table 13   Annual embodied energy consumption in Adelaide City in 2001

Embodied energy (EE)	Total Energy consumption (GJ)	Total GHG emissions (t CO_2-e)
Building	3,778	264.5
Roads	799	51.9
Water supply network	112	8.0
Wastewater system	285	20.2
Road vehicle fleet	1,417	96.4
Total	6,391	441.0
Average EE (or CO_2-e) per capita	22	1.5
Average EE (or CO_2-e) per household	39	2.7

Source: Modified figures from Troy et al. (2003); Note Adelaide City is a component of Adelaide

7.1.1   Energy embodied in common water assets

The basic factors that influence the embodied energy impact of water and wastewater piping systems are:

- Pipe size - the bigger the pipe the more embodied energy;

- Amount of materials used - more materials, higher embodied energy;

- Pipes produced with significant recycled material - these materials usually have a lower overall embodied energy;

- Materials with a low embodied energy coefficient - the lower the coefficient the lower the embodied energy;

- Piping systems, which are more durable and have a longer life expectancy - less repair and replacement leads to lower embodied energy over the life cycle of the system; and

- Piping systems, which can last longer with appropriate maintenance - extending life, rather than replacing reduces embodied energy for that system over its life cycle.

Embodied energy coefficients are usually expressed in gigajoules (or megajoules) per unit of mass, where the unit is the typical one used to describe that item. For water and wastewater pipes expressing the embodied energy coefficient in lineal metres instead of using mass will significantly impact a comparison of different materials. For example, plastic pipes such as PVC have approximately double the embodied energy of ductile iron pipes when compared in terms of a unit of mass, but if the comparison is made in a unit of length then PVC outperforms ductile iron due to its relatively light weight.

Ambrose et al (2002) estimated embodied energy for different PVC pipe products on the basis of length (linear metre) and compared it with other pipe materials commonly used for urban water and wastewater systems. A summary of the embodied energy coefficients is listed in Table 14.

According to Ambrose *et al*. (2002), plastics for a piping solution have significant advantages in terms of embodied energy due to the lighter weight per lineal metre. The embodied energy value obviously increases with the mass of pipe. For example ductile iron pipe ranges from 632 MJ/m for pipe of 110 mm internal diameter, through to 2180 MJ/m for pipes of 331 mm internal diameter. PVC pipes (PVC-M and PVC-0) of nominal diameter of 300 mm range from 1358 MJ/m to 2041 MJ/m, and PE (80B and PE100) pipes around 2000 MJ/m for similar diameter pipes.

Table 14   Embodied energy coefficients for pipe types

Pipe Type	Embodied Energy (MJ/kg)
Ductile Iron	38.2
Ductile Iron Concrete Lined (DICL)	40.2
PVC-U*	74.9
PVC-M**	76.6
PVC-O***	87.9
PE80B	75.2
PE100	75.2

*Un-plasticised; ** Iplex modified PVC (PVC-M) pressure pipes; ***Oriented PVC (PVC-O) pipes for pressure applications. Source: Ambrose et al. (2002)*

In relation to water systems, Pullen (1999) estimated the embodied energy for water supply, wastewater and stormwater services in an Adelaide suburb were 0.7, 2.4, and 1.6 GJ per house per year respectively (total of 4.7 GJ/(house*a)). The comparison of the conventional centralised approach to water supply with on-site collection and storage indicates that in areas with reliable rainfall on-site capture and storage has lower energy consumption. This however will be influenced by the size and material type of the tank. Pullen (1999) also compared embodied energy for two types of water storage tanks of three different sizes (Table 15). This table demonstrates that embodied energy can vary depending on the size and material type, with the reinforced concrete tank having more than twice the embodied energy of the similar sized PVC lined steel tank.

Table 15   Embodied energy of water storage tanks

Tank size	PVC membrane lined steel			Reinforced concrete		
	EE (GJ)	Life expectancy	Annualised energy	Embodied energy	Life expectancy	Annualised energy
Unit	GJ	Years	GJ/a	GJ	Years	GJ/a
34 kL	13	50	0.3	42	75	0.6
68 kL	24	50	0.5	58	75	0.8
113 kL	36	50	0.7	78	75	1.0

Source: Pullen (1999)

Domestic energy consumption in Sydney was estimated to be 19 GJ/capita in 1970 (Kalma et al., 1972) and 13 GJ/capita in 1976 (Newman, 1982). Since then this figure has almost doubled to about 35 GJ/(cap*a) (Lenzen et al., 2004). This is because Lenzen's (2004) research was based on the input-output analysis which is considered indirect energy consumption.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made from this analysis and given current knowledge of our water systems:

Energy use by utilities

- Energy use by utilities was 7.1 PJ and comprised a relatively small component (0.2%) of total urban systems energy use in 2006-07.

- Energy requirements for water supply and wastewater disposal vary significantly across different cities (as per Table 1 and Table 2), with most of these variations being explained by local conditions including pumping long distances, lifting water to elevation and water and wastewater treatment requirements.

- Pumping water long distances and/or to overcome gravity uses substantial energy. Sourcing both recycled water and desalinated water closer to the city may actually require less energy in some cases. Further analysis is warranted to investigate the pumping efficiency of urban water systems.

- If tertiary treatment of wastewater is already required, then reuse opportunities are more favourable presuming energy needs for pumping after treatment are not overly high. This is because most high-quality reuse options require tertiary treatment or equivalent prior to membrane treatment or reverse osmosis.

- Use of biogas and sourcing energy from sources other than coal based electricity will significantly reduce greenhouse gas emissions; and

- Efforts to minimise energy-related greenhouse gas emissions from water service operations need to focus attention on the use of imported electricity.

Energy use for hot water use

- Energy usage associated with water heating is significantly more than the energy use of water service providers. This project estimated residential water heating uses between four and eleven times as much energy as water utilities in 2006-07 (or 0.5 to 2.5% of total urban systems energy use).

- Energy use for residential water heating was approximately 46 PJ in 2006-2007 for the 12,048,000 people in the Australian cities studied in this report. A relatively small reduction in residential hot water use could more than completely offset total existing energy use for water service provision. Water utilities have the opportunity to influence a far larger pool of greenhouse gas emissions associated with energy use through water use policy (both residential and potentially industrial), than their direct energy use.

- Improved monitoring of energy associated with water end-use is warranted. Improved public reporting of this energy is also warranted. Some utilities are already reporting the estimated greenhouse gas savings attributable to water conservation measures (Sydney Water 2006). Reporting the total pool of this energy presents a more complete picture of a water utility's energy saving opportunities.

- It is suggested that WSAA voluntarily adopt and encourage reporting of energy use associated with water use by customers. This would require (1) development of appropriate data definitions, (2) monitoring programs to acquire data and (3) development of an agreed energy calculation methodology. Such information would help confirm the magnitude of current energy use associated with water use and thereby improve estimates of the influence of water supply options on energy use and associated greenhouse gas emissions. It is possible that

collaboration with energy supply bodies (e.g. electricity and/or gas service providers) could improve the quality of information in this effort.

- Industrial hot water use is expected to similarly represent a significant use of energy related to water use however improved data are necessary to characterise this.

- Improved definitions of energy associated with "treatment" and "transport". This is required to help distinguish "pumping" energy used at treatment plant sites. Similarly, improved analysis using more substantial data sets is warranted to better characterise the energy use with different water and wastewater treatment processes and pumping systems.

- There is generally little information available regarding the energy use of decentralised systems (e.g. rainwater tanks, backyard bores). The influence of increased uptake of decentralised water supply options on energy warrants further analysis.

Future trends

- If national residential water consumption could be constrained to 150 L/(cap*d) then minimal additional energy would be required because minimal additional water supplies would be required on the presumption that current supplies continue to yield at existing rates.

- The wide-spread adoption of low energy hot water heating options (e.g. solar hot water) could dramatically reduce greenhouse gas emissions which are projected to grow if per-capita residential water consumption remains at or above 225 L/capita/day.

- The social and economic consequences of moving to lower per-capita water consumption levels requires further investigation. For example, the current low water consumption in South East Queensland during prolonged low rainfall conditions may not be socially acceptable or maintained over the long term, let alone applied to Australia as a whole. Nonetheless, if this water consumption was adopted nationally it would mitigate the need to build significant new supplies for urban regions *despite* the large increase in population over the next two decades.

- If all new water demand (to meet 300 L/capita/day residential use for 15.8 million people) was sourced from desalination - an extreme case - the energy required for water services provision would grow by approximately 400% (growing from 7 to 36 PJ). However this would represent approximately 0.% of projected total urban systems use in 2030.

- If demand management strategies can contain average residential water use to 225 L/cap/d then 21 PJ (an additional 14 PJ) of energy would be required if all new water was supplied by desalination. Options meeting new supply with 40% desalination, 40% reuse and 20% new sources were estimated to require an additional 9 PJ taking total consumption to 16 PJ/a.

- At residential water consumption levels of 300, 225 and 150 L/(cap*d) some 80, 68 and 52 PJ of energy respectively would be required at the point of use to heat water. This assumes indoor use of 65%, 75% and 85% at these three water consumption levels.

- Characterisation of a longer period of time would help detect longer-term drivers and also smooth results for local influences on particular systems which may have affected the 2006-2007 result.

- This report has been characterised 2006-2007 in some detail. Analysis of a longer period of time would be essential to identify underlying trends and to remove variability potentially influencing some cities in the particular year analysed.

Greenhouse gas emissions

- Most utilities currently rely on electricity generated from greenhouse gas intensive fuels (brown and black coal). A shift to cleaner energy sources, such as electricity generated from

natural gas, would significantly reduce greenhouse gas emissions from fuel usage in the water sector.

- Relatively little data exists for fugitive greenhouse gas emissions in the water cycle. Compilation and analysis of such data is warranted.

- In the case of water heating, the link between energy use and greenhouse gas emissions is not linear but affected by appliance stock and energy sources. Further analysis is necessary to characterise these linkages and estimates of greenhouse gas emissions savings associated with any particular strategy.

Need for analysis beyond individual utilities

Where more than one utility is involved through the supply chain for water and wastewater services it becomes increasingly difficult to get a true picture of the total energy required to provide water and wastewater services. It also becomes increasingly difficult to estimate the impacts of alternative strategies for future water provision. Alignment of strategies through the water cycle will be necessary to ensure that the best "whole of system" outcomes or that the lowest possible "whole of system" greenhouse gas emissions rates are achieved.

7.2   Other issues

There are a range of other issues that warrant consideration but were not the focus of this study. They are listed below to promote further discussion:

- Implications for greenhouse gas reduction strategies for water utilities. Should water utilities greenhouse reduction efforts be restricted to the direct energy use associated with water and wastewater services? Or should it also include fugitive greenhouse gas emissions for which relatively little information is currently available? Similarly how should "life-cycle" emissions including from hot water use, energy embodied in materials and chemicals used in the provision of water, and other aspects such as employee transport be recognised?

- Private participation in water management is increasing and in places water cycle management is being fragmented and decentralised systems are growing. System-wide information will be necessary in future to enable decision-making that provides the most cost and energy-efficient solutions. Financial analysis is also necessary to ensure that the least cost solutions are found, not just those that save the greatest amount of greenhouse emission for the lowest overall cost.

Data needs

- Improved data for industrial hot water use and associated energy (possible use of Life Cycle Analysis models and methods);

- Improved definitions of treatment and transport energy will help separate the influence of these two components of water and wastewater systems;

- Improved estimates are necessary for scope 3 emissions as relatively little data existed in this area;

- Improved spatial attribution of energy data to treatment and transport. For example mapping of energy density associated with water and wastewater treatment and transport. These data will be necessary to improve assumptions regarding future water supply options and the influence they have on water and wastewater energy use;

- Usage of energy consumption data (at household and industry level) to improve estimates of energy consumption associated with water use;

- Analysis is recommended on other influences which can also contribute to the increasing need for energy in urban water systems. For example the influence of improved water treatment standards on energy use.

- Consideration of other influences outside water utilities control including the effect that urban form (e.g. housing stock and type, as well as appliances) has on the overall water balance, water and energy end-use associated with water utilities, and total urban system. Clearer definition of the "total urban system" may warrant consideration with regard to how much influence an individual may have on their contribution to energy use and greenhouse gas emissions.

- Consideration of future carbon price pathways will also help water service providers (and others) identify most cost-effective options.

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# APPENDIX 1. GEENHOUSE GAS EMISSIONS CATEGORIES

The Department of Climate Change's 'National Greenhouse Accounts (NGA) Factors' (2008) aims to provide a consistent set of emission factors for a variety of purposes. This workbook adopts the emissions categories of the international reporting framework of the World Resources Institute/World Business Council for Sustainable Development. The framework is known as The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard ('The GHG Protocol') and is available at www.ghgprotocol.org. The GHG Protocol defines three 'scopes' of emission categories:

Scope 1 covers direct emissions from sources within the boundary of an organisation such as fuel combustion and manufacturing processes.

Scope 2 covers indirect emissions from the consumption of purchased electricity, steam or heat produced by another organisation. Scope 2 emissions result from the combustion of fuel to generate the electricity, steam or heat and do not include emissions associated with the production of fuel. Scopes 1 and 2 are carefully defined to ensure that two or more organisations do not report the same emissions in the same scope.

Scope 3 includes all other indirect emissions that are a consequence of an organisation's activities but are not from sources owned or controlled by the organisation.

A simplification of this is presented in Figure 18.
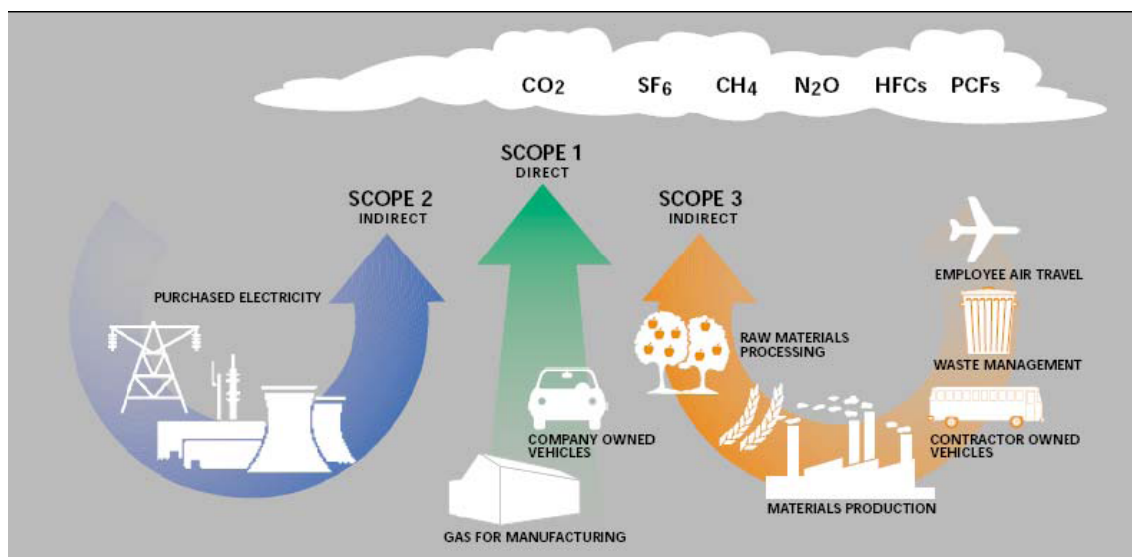
Figure 18   Scope of greenhouse gas emissions

Source: New Zealand Business Council for Sustainable Development

APPENDIX 2 RAW DATA FROM WATER UTILITIES 2006-07

	Sydney Water	Sydney Catchment Authority	Melbourne Water	Yarra Valley Water	Water Corporation	Brisbane Water	Gold Coast Water	SA Water	Watercare	Metrowater
Population served	4,300,000		N/A	1,571,650	1,538,000	1,006,000	492,000	1,095,000	1,232,000	431,000
Water supplied (GL)	509	507	412	160	235	113	65	159	136	54
Residential Water Supplied (GL)	315		?	107	170	61	40	111	N/A	
Wastewater collected (GL)	487		296	108	119	86	47	88	104	53
Total energy water supply – pumping (GJ)	476,298	1,211,662	86,185	16,321	423,000	28,245	39,416	995,041	39,327	1,711
Total energy water supply – treatment (GJ)	186,009		12,860	Not reported	409,000	246,337	9,234	55,418	56,749	
Total energy wastewater – pumping (GJ)	119,916		436,467	9,686	92,800	39,726	50,030	32,064	37,978	1,573
Total energy wastewater – treatment (GJ)	698,205		645,715	38,970	213,000	138,028	119,389	185,194	273,293	100
Other Energy Demand (GJ)	220,522	30,316	67,000	26,970	162,700	49,070	39,461	123,240	23,157	
Total energy all demands (GJ)	1,700,950	1,241,979	1,248,227	91,947	1,300,500	501,406	257,530	1,390,957	430,504	
Greenhouse gas emissions - Total Reported (or FFC) for Energy Related Sources (t CO_2-e)	448,282	326,110	233,633	28,482	312,850	138,000	74,505	392,486	31,883	

Source: This survey

APPENDIX 3 ADDITIONAL DATA ON RESIDENTIAL ENERGY USE AND URBAN SYSTEMS

Table 16 shows the change in energy demand by city over the period 1996 to 2005 (See also Figure 19). This shows the greatest growth occurred in Gold Coast and Brisbane, with energy consumption increasing in the Gold Coast by 60% over this period. This is due to the rapid population growth in South East Queensland, with Brisbane and Gold Coast population growing at an annual rate of 1.9% and 3.5% respectively between the period 1997 and 2002 (ABS, 2003).

**Table 16   Residential energy use by city (PJ)**

	Sydney	Melbourne	Brisbane	Gold Coast	Perth	Adelaide	Total (for Aust. cities to left)	Auckland*
1996	67.7	102.1	17.9	4.3	22.0	21.4	235.8	16.4
1997	69.9	103.3	18.4	4.6	22.4	22.0	241.2	17.1
1998	70.7	105.3	18.9	4.8	23.5	22.4	246.2	17.5
1999	72.2	103.4	19.5	5.0	23.9	22.6	247.4	17.8
2000	74.1	105.1	20.0	5.2	24.4	22.9	252.3	17.8
2001	75.1	106.6	20.4	5.4	24.2	23.4	256.0	18.5
2002	68.0	107.8	20.7	5.6	25.2	21.5	251.6	19.0
2003	69.2	118.8	22.2	6.1	25.7	22.9	266.5	19.1
2004	71.1	117.2	23.8	6.6	25.6	24.9	269.8	20.0
2005	73.8	120.0	25.4	7.1	25.3	26.0	278.2	20.9

*Source: ABARE (2006), *MED (2008)*

**Table 17 Projected population and total urban energy use - 2030**

	Projected Population 2030	Estimated Total Energy Consumption (PJ) 2030
Sydney	5,592,000	1,360
Melbourne	4,573,000	1,364
Brisbane	1,509,000	592
Gold Coast	800,000	314
Perth	2,177,000	1,098
Adelaide	1,182,000	275
Total	**15,833,000**	**5,002**

Source: Projected Population; WSAA(2005). Estimated energy from Cuevas-Cubria, C. and Riwoe, D. (2006) Australian Energy: National and State Projections to 2029-30 - ABARE Research Report 06.26. The energy projection for Cities taken as pro rata based on proportion of total State population residing in City.
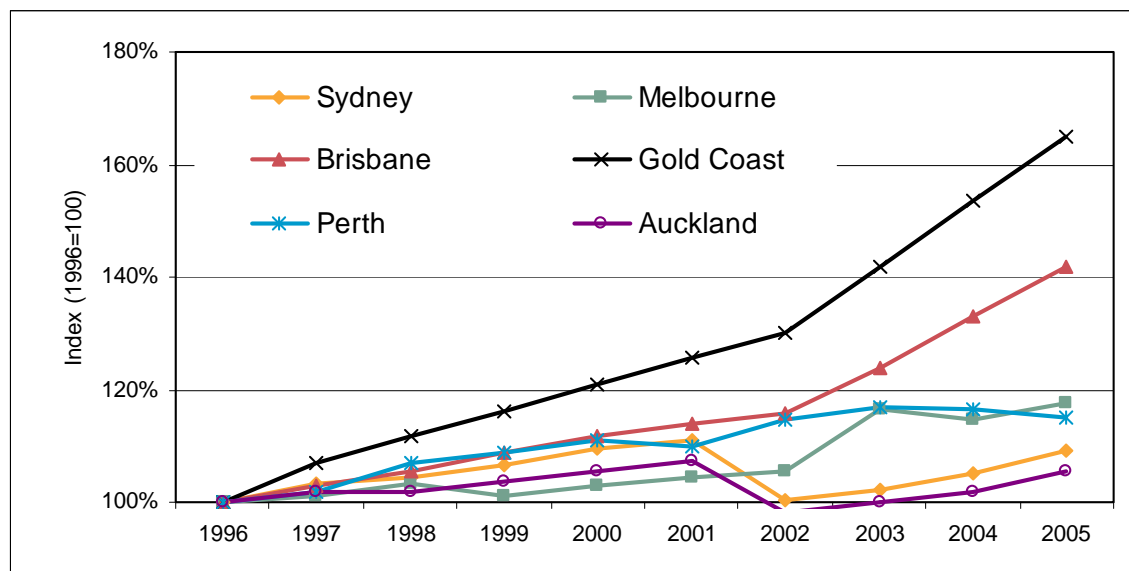

Figure 19   Change in the residential energy use for cities (1996-2005)

The greenhouse gas emissions for different urban areas (Figure 20 and. Figure 21) show the rate of increase of GHG emissions from 1996. This shows the greatest increase has been recorded by the Gold Coast, which is relatively small proportion of total emissions but GHG emissions have accelerated in response to the rapid increase in population recorded over this period. All other cities have increased their GHG emissions by at least 20% over this period.
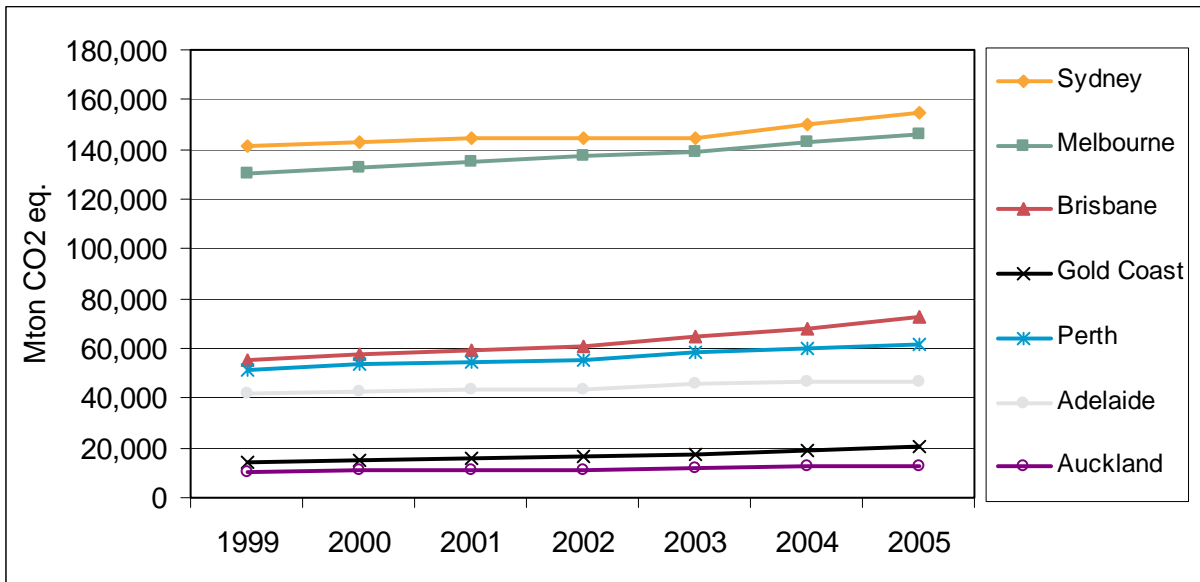
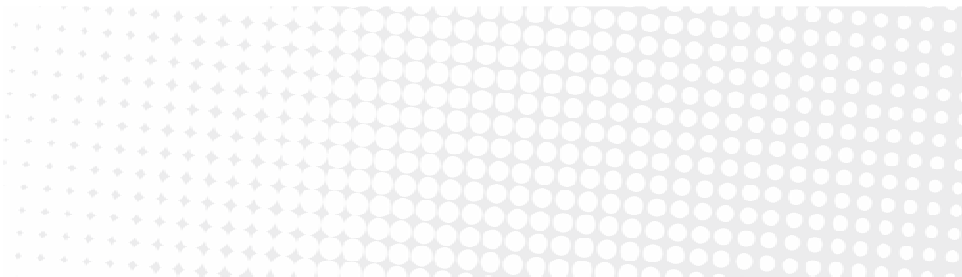**Figure 20**   GHG emissions for cities (Mt CO$_2$-e. 1996-2005)
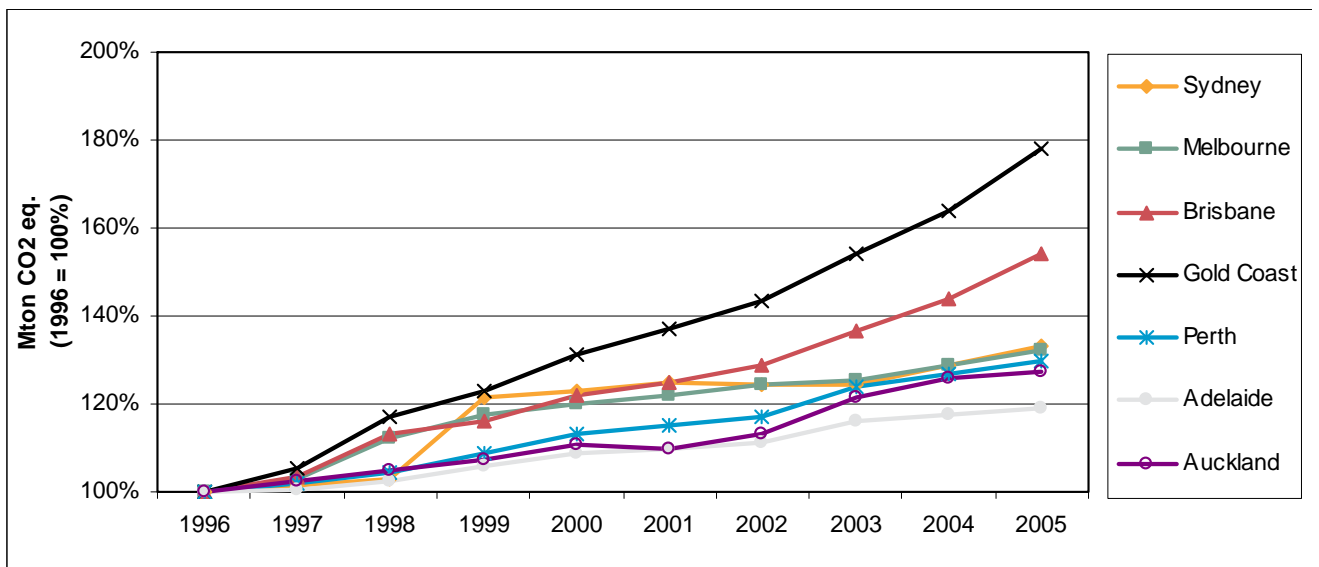
Figure 21   Change in the GHG emissions for cities (1996-2005)

Australia's population is increasingly being concentrated into large cities, with more than 85% of Australians accommodated in urbanised areas. A similar trend is occurring in New Zealand. Table 18 depicts the concentration of population in Australian cities. Emissions from electricity generation comprise 70% of Australia's stationary energy greenhouse gas emissions, with majority of the demand for electricity being driven by industrial and residential sectors of the major urban centres (Pears, 1996).

Table 18   **Concentration of population in urban centres**

	Sydney	**Melbourne**	**Brisbane**	**Gold Coast**	**Perth**	**Adelaide**	**Auckland**
% by State	63	73	45	13	74	74	-
% by National	21	18	9	2	7	6	33

The population density of a city is an important consideration in evaluating energy demands of a city, as often there is an inverse relationship between population density and energy demand per capita with increasing density associated with reduced energy consumption per capita. Perth has the lowest population density and the highest energy consumption per capita, while Auckland has the highest population density and lowest energy consumption per capita.

Energy Use in the Provision and Consumption of Urban Water
in Australia and New Zealand, June 2008