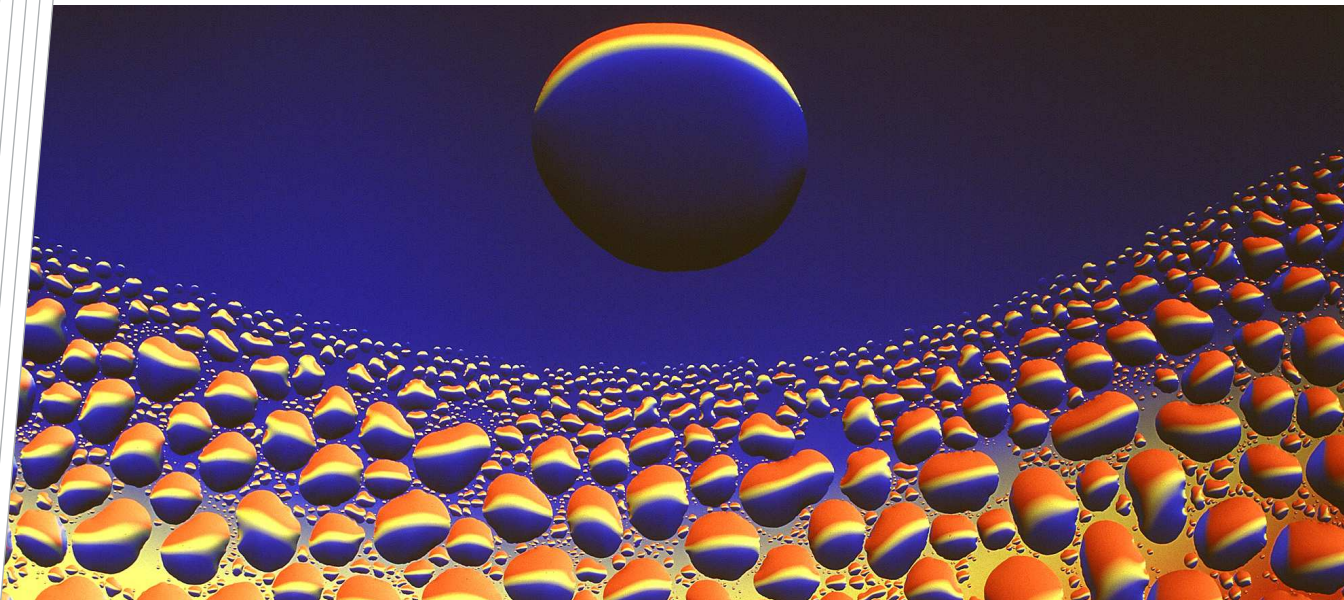


## Energy use in the provision and consumption of urban water in Australia and New Zealand

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A. Gregory and M. Hall

10 December 2008



Water for a Healthy country Flagship Report series ISSN: 1835-095X

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ISBN: 978 0 643 09616 5

Citation: Kenway, S.J. et al., 2008. Energy use in the provision and consumption of urban water in Australia and New Zealand. CSIRO: Water for a Healthy Country National Research Flagship.

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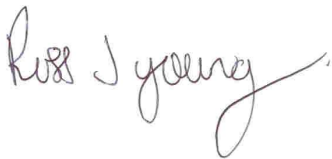
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## FOREWORD

There is a strong nexus between water and energy. Water is required for the production of energy, particularly electricity and energy is consumed in providing vital urban water and wastewater services to cities and towns across Australia. The urban water industry in the past has collected and analysed its energy and greenhouse gas emissions data on an individual utility basis and this was generally reported in the National Performance Report and formerly WSAA facts. The data on greenhouse gas emissions was reported without any context or comparisons with other industry sectors. For instance, although some utilities knew they were large users of energy in relation to other businesses, they had little idea how they compared to the total energy consumed by a city or why there were wide variations between utilities. No body of work aggregated the data to provide a national perspective on energy use by the urban water industry, including energy use associated with water used at the domestic level, in particular hot water.

As a result of this report, prepared by the CSIRO for WSAA, we now know that energy use varies greatly between water utilities in the different cities, influenced by each city's geography and its water and sewerage systems. We also know that the provision of urban water services uses relatively little energy in relation to the whole economy and compared with other sectors of the economy. This report provides a contextual understanding of energy use in relation to the total urban water cycle and has identified where reductions in the greenhouse gas footprint of the urban water industry and households may be possible.

A thorough understanding of the urban water industry's energy use and greenhouse emissions is particularly crucial given the imminent introduction of a new national greenhouse accounting methodology and the design of a carbon pollution reduction scheme. We are confident that the body of knowledge and recommendations contained in this report will assist the urban water industry adapt to operating in a carbon-constrained economy.



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## ACKNOWLEDGMENTS

The authors would like to thank Ross Young, Nathan Smith, Adam Lovell and Peter Donlon, of WSAA for their support, encouragement and co-funding. The authors would also like to thank participating utilities including:

- Watercare NZ (Alistair Shanks and Ralph Viljoen)
- Gold Coast Water (Susan Quirk and Kylie Catterall)
- Melbourne Water (Erik Ligtermoet)
- Sydney Water (Philip Woods)
- Sustainability Victoria (Fraser Chitts)
- Brisbane Water (Keith Barr)
- Water Corporation (Miles Dracup)
- SAWater (Tim Kelly)
- Sydney Catchment Authority (Imraan Bashir) and
- Metro Water NZ (Chayne Zinsli).

Thanks to David Flower and George Grozev for reviewing drafts of this report.

## EXECUTIVE SUMMARY

This report is the outcome of a CSIRO and Water Services Association of Australia (WSAA) study to improve understanding of energy use in the provision of urban water services.

The study focused on the energy used by ten water utilities operating supply and waste water systems in seven cities in Australia and New Zealand: Sydney, Melbourne, Brisbane, Gold Coast, Adelaide, Perth and Auckland.

The report provides a first picture of water services energy use and associated greenhouse gas emissions. The report compares this energy use with energy use for residential water heating and with the energy use of the city. City energy use is calculated as a proportion of state-wide energy use. Fugitive greenhouse gas emissions were not analysed due to limited existing data.

The report presents three future scenarios for water consumption and two scenarios for future water sources. Energy implications are assessed. Recommendations to support ongoing improvements in energy efficiency for the urban water industry and the wider 'urban water system' are also made.

### Key findings

Total energy use by water utilities in Sydney, Melbourne, Perth, Brisbane, Gold Coast and Adelaide in 2006/07 was 7.1 petajoules (PJ) and met the needs of 12.5 million people (resulting in an Australian average of 590 megajoules per person per year [MJ/(cap\*a)]). This figure is approximately 0.2% of total urban energy use and less than 15% of the energy used for residential water heating – modelled as at least 46 PJ for 2006/07. Energy use by Auckland water utilities comprised 0.43 PJ and met the needs of some 1.2 million people (349 MJ/(cap\*a)).

### Characteristics of energy use by water utilities

Energy use for pumping and treating supply water and wastewater varies significantly from city to city. Local conditions including water use, topography and water sources have a major influence on energy use values. Pumping water from sources located at considerable distance from cities contributes significantly to energy use in some cities because ongoing low rainfall periods have diminished local storages.

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, re-use opportunities may become more cost-effective as the additional energy required for re-use may be relatively minor depending on energy requirements after treatment (e.g. for pumping).

Imported electricity, representing 76% of energy used by water utilities, is the main source of energy-related greenhouse gas emissions by the water industry. Maximising renewable energy opportunities such as biogas capture, mini-hydros and sourcing low emissions electricity from the grid will significantly reduce greenhouse gas emissions.

Although information on embodied energy is sparse, the energy consumed in operating urban water systems appears to be significantly greater than the annualised energy embodied in urban water infrastructure.

### Energy use associated with residential water users

Energy use for residential water heating in Sydney, Melbourne, Perth, Brisbane, Gold Coast and Adelaide (46 PJ) represented 1.3% of energy use in the total urban system. 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.

This means that:

- At national level, a 15% reduction in the use of residential hot water or an equivalent increase in the efficiency of residential hot water systems would completely offset the total energy used by the utilities providing water to those households in 2006/07. However care must be made interpreting this for any particular city.
- Residential water demand management strategies should be targeted at energy-intensive end-uses, such as showers and washing machines as these can significantly reduce household energy demand and associated greenhouse gas emissions. Analysis showed that shifting to a WELS 3-star shower rose would decrease energy consumption for hot water by approximately 50% for households with considerably greater-than-average water use.

Energy use associated with industrial and commercial water use (e.g. water heating) is anticipated to be of similar magnitude to the energy for residential water heating. However, only minimal data could be found to verify this and consequently this information should be sourced as a priority.

### Future water utility energy use

The future scenarios analysed in this report were based on the assumption that population would grow from 12.1 million to 15.8 million by 2030 (total for Sydney, Melbourne, Brisbane, Gold Coast, Adelaide and Perth). A number of scenarios were developed with regard to differing levels of residential per capita water consumption and potential additional water supply sources. Three levels of per capita water consumption were analysed – 150 L/(cap\*d), 225 L/(cap\*d) and 300 L/(cap\*d) – and two future water source scenarios were analysed – a ‘mix of sources’ (40% desalination, 40% re-use and 20% new sources) and 100% desalination (an extreme case). The energy required in 2030 for these different water supply scenarios and its percentage of the total urban system energy consumption is provided in Table 1.

**Table 1 Energy demand in 2030 for water at three residential water consumption levels considering two supply scenarios**

Residential water consumption levels L/(cap*d)	Mix of supply sources (40% desalination, 40% re-use, 20% new sources)			100% desalination (extreme case)		
	Total energy required (PJ)	% increase for utilities (from 2006/07 use of 7.1 PJ) (%)	% of total urban system (%)	Total energy required (PJ)	% increase for utilities (from 2006/07 use of 7.1 PJ) (%)	% of total urban system (%)
300	26	260	0.5	36	400	0.7
225	16	130	0.3	21	200	0.4
150	7	0	0.1	7	0	0.1

*Estimates are based on current yields and assume the yield and energy intensity of sources providing water in 2006-07 remain constant. Under these assumptions an additional 1400, 700 and 0 GL respectively would be required to meet residential consumption levels of 300, 225 and 150 L(cap\*d) respectively for 15.8 million people.*

The per capita consumption levels chosen are representative of residential water use in Australia in 2006/07 which ranged from 166 to 303 L/(cap\*d)(approximately 153 to 281 kL/property/a) and averaged 217 L/(cap\*d). However some of these cities were operating under severe water restrictions including a total ban on outside watering. Consequently achieving 150 L/(cap\*d) may not be socially or economically acceptable in the long term.

For the scenarios analysed, the amount of energy required to deliver water services in 2030 ranges from 7 to 36 PJ/a representing growth of 0 to 29 PJ from 2006/07 levels. This range represents between 13% and 45% of the anticipated energy use for residential water heating.

Although this report highlights the relatively small contribution of water utility services to total urban energy consumption, it also highlights the role that water conservation can play in reducing the energy consumed in providing future urban water services. Water utilities should therefore communicate to their customers the benefits of water conservation in terms of reduction in greenhouse emissions and significant cost savings in relation to water and energy bills.

This report has demonstrated that a large amount of energy consumption can be influenced by urban water use and consequently urban water policy choices.

## **Key recommendations**

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

- continue with a detailed mapping of internal energy use and associated greenhouse gas implications to understand its situation
- continue with a program of improving energy use efficiency in water utility operations
- alert Federal and State Governments to the energy and greenhouse gas implications of improving the efficiency of residential hot water production where the scope for gains may be substantial
- 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 such as desalination, recycled water and decentralised systems (e.g. rainwater tanks, backyard bores) and factor these into water supply planning and
- improve monitoring, analysis and reporting of end-use energy (particularly residential hot water) to help confirm the magnitude of energy use associated with water consumption and future trajectories, and improve estimates of the influence of water supply options on energy use.

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## ABBREVIATIONS

a	annum (year)
ABARE	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 <sub>2</sub> -e	carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EE	embodied energy
FFC	full fuel cycle
GHG	greenhouse gasses (GHGs common to the water industry include carbon dioxide (CO <sub>2</sub> ), methane (CH <sub>4</sub> ) and nitrous oxide (N <sub>2</sub> O)).
GJ	gigajoule (10 <sup>9</sup> joules; 1 GJ/ML = 1 MJ/m <sup>3</sup> = 0.277 kwh/m <sup>3</sup> )
GWh	gigawatt hour (10 <sup>6</sup> kWh)
HH	household (on average containing approximately 2.5 people)
HWS	hot water system
J	joule (one watt second)
kWh	kilowatt hour (3.6 MJ or 3.6 x 10 <sup>6</sup> J)
L	litre
L/(cap*a)	litre per capita (person) per year
L/(cap*d)	litre per capita (person) per day
m	metre
MJ	megajoule
ML	megalitre
NWC	National Water Commission
PJ	petajoule (10 <sup>15</sup> joules)
STP	sewage treatment plant
t	metric tonne (1000 kg)
WSAA	Water Services Association of Australia

# 1. INTRODUCTION

This report is the outcome of a joint initiative by the Water Services Association of Australia (WSAA) and CSIRO to improve the understanding and management of energy use by wholesale and retail water utilities and in urban water more generally.

The water industry is one of the first industries to be significantly impacted by recent climate variability – increasingly being attributed to climate change. Reduced rainfall and declining inflows have placed extreme pressure on traditional water supplies and forced reconsideration of current water use practices.

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

Most proposed new water sources are more energy-intensive than traditional sources (Medeazza and Moreau 2007). This means that they use more energy per unit of water provided at specified quality to the consumer. The increment in energy use creates a real dilemma because it creates 'positive feedback' in several systems. For example, when the energy is sourced from coal-fired electricity, it contributes further greenhouse gas emissions and consequently adds to ongoing climate change. In addition, energy generation itself requires water and this can further compete with the water needs of cities.

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, businesses, government and the wider economy.

It is argued here that widening the perspective offers 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 energy use 'beyond the boundaries' under the direct control of water utilities. 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. This report aims to contribute to this space by quantifying some of the energy 'boundaries' as well as clarifying some of the linkage points between water and energy use.

## 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 when water is pumped, treated or pressurised.

Energy requirements vary significantly from city to city, depending on local factors such as topography, location and quality of water sources, pipe dimensions and configurations, and treatment standards required. 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).

To date, limited analyses of the energy implications of water strategies have been undertaken and energy use is rarely mentioned in urban water strategies (DSE 2006; Qld Government 2006; Water Corporation 2005) despite considerable public commitment and effort from individual utilities.

The importance of climate, energy and water to the past, present and future development of both urban and rural Australia has been historically understated. Human health and wellbeing, settlement patterns, economic wellbeing, and environmental conditions are all strongly influenced by these three factors (Proust et al. 2007). Issues associated with and links between climate, energy and water will become more critical in future.

In early 2008, Australia ratified the Kyoto Protocol and instigated a new climate change policy including a commitment to introduce a carbon pollution reduction scheme by 2010. Consequently Australian planners must now consider the energy and greenhouse gas emissions implications in the decision-making process with increased rigour. New Zealand ratified Kyoto in 2002. In addition to policy, pressure will also be exerted on strategies and technologies as energy prices continue to rise. Addressing these implications through policy and practice remains a significant challenge for the management of sustainable urban water services.

## Objectives and focus of this report

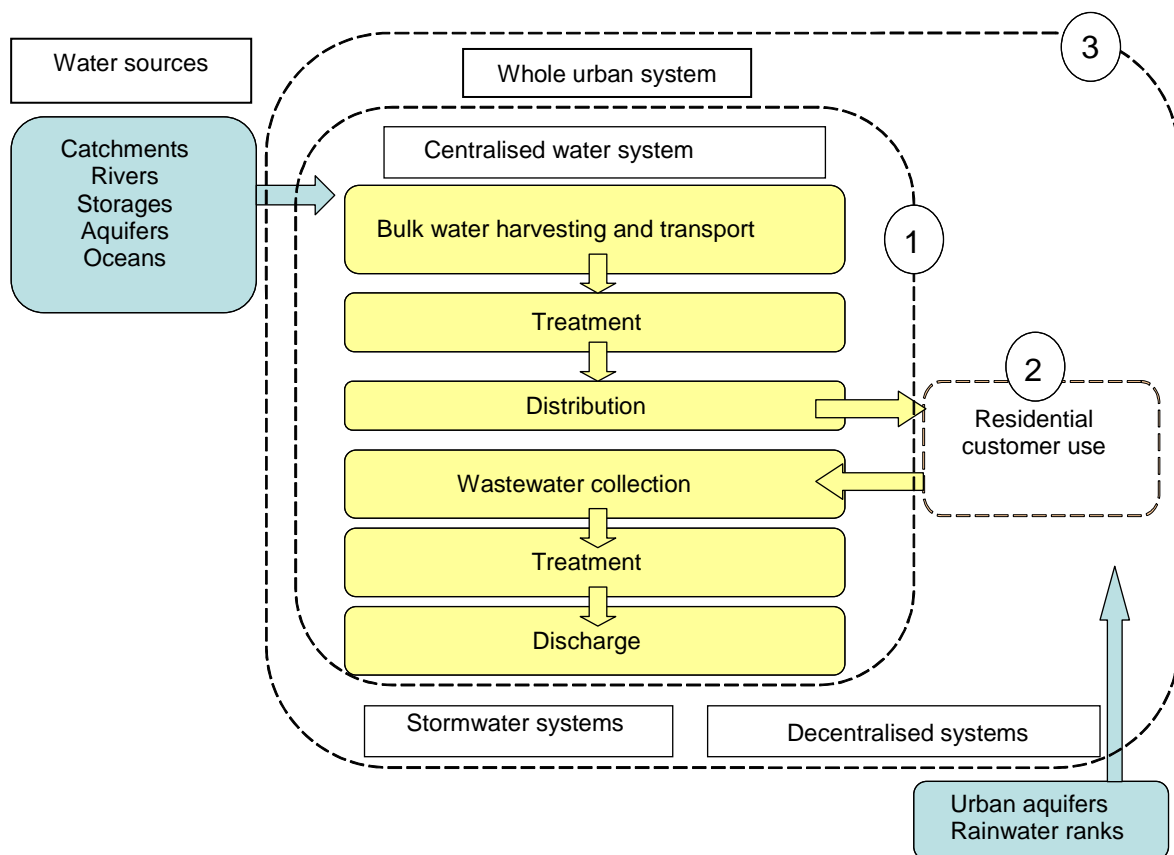
Key objectives of this study were to:

- provide a first national snapshot of energy use through the urban water system including an estimate of 'whole-of-system' energy use from bulk water providers through to retail distribution
- create context for the energy dialogue by expressing utility energy use within the 'total urban system' and residential energy use for water heating
- estimate how future water management choices may influence energy demand and
- undertake preliminary analysis of energy-related greenhouse gas emissions and embodied energy use in the water sector, based on available data.

Energy consumption was evaluated for three 'system boundaries'. The first boundary was the centralised system for the provision of urban water services (see circled 1 in Figure 1) and included all energy use including bulk water harvesting, transfers, contracted treatment operations and wastewater discharge. The second boundary was focused on energy use associated with residential water use, particularly heating. The third boundary attempted to quantify total urban energy use.

Centrally managed water supplies were the focus because they represent the largest volumes of water moved through cities. Energy use associated with the stormwater system and decentralised supplies were not specifically analysed nor was energy use associated with rainwater tanks and backyard bores. This is because these options currently represent relatively minor components of urban supply nationally, although they may be important in individual cities.

Residential use of energy associated with water was considered because it was understood to represent a significant portion of the 'end-use' pool of energy (e.g. Wolff and Nelson 2004). Additionally, data sets to estimate the amount of energy associated with residential uses were assumed to be generally more available than other end-uses including commercial and industrial use of energy associated with water.



**Figure 1 Water cycle and urban system components evaluated for energy use**

Total urban systems energy use was considered in order to create context for Boundaries 1 and 2 and also to introduce the concept of urban metabolism into the project. 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 associated energy, it also simultaneously considers total energy flows through the cities. The urban metabolism model enables a system-wide understanding of a city's energy and materials flows that can place specific components, such as water and wastewater services, within the context of the overall urban system. (Newman 1999; Pamminer and Kenway 2008; Sahely et al. 2003). This helps provide a more quantitative framework for decision-analysis at city scale.

## Cities evaluated

The project focused on major urban systems in Australia and New Zealand through 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) South East Queensland (Brisbane Water and Gold Coast Water), 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). The Australian cities evaluated are expected to cater for the bulk (over 90%) of Australia's forecast population growth through to 2030.



**Figure 2** Location of cities examined in the project

## Structure of this report

- Chapter 2 describes energy use by water utilities based on the survey undertaken for this study.
- Chapter 3 considers and estimates energy use associated with the consumption of water. This has a particular focus on residential water heating.
- Chapter 4 describes the energy use in our 'urban systems'.
- In Chapter 5, the key data from the three previous chapters are drawn together to place utility-level energy use in context. The chapter then forecasts future energy use associated with the provision and consumption of urban water by considering future potential water supplies for three levels of residential water use.
- Chapter 6 presents summary information on embodied energy associated with urban water systems.
- Conclusions and recommendations are made in Chapter 7.
- Definitions are in Chapter 8.

## 2. ENERGY USE BY WATER UTILITIES

In this section, data on energy use associated with pumping and treatment for both water supply and wastewater disposal (energy used by utilities) for each city is reported. In some cases, more detailed data allow an analysis of the effect of both plant capacity and treatment technology on energy demand and give some indication of energy requirements of possible future supply schemes. All energy data are quoted in gigajoules (GJ; 1 GJ = 10<sup>9</sup> joules).

### Methodology

The primary methodology for characterising energy use by water utilities through the urban water system involved utilities compiling data to a pro-forma spreadsheet prepared by CSIRO. Detailed data on energy consumption were sourced from water utilities for 2006/07. Overview information on energy sources, historic trends of energy use and related data were also sought as was a breakdown of greenhouse gas emissions and current and forecast water use and end-use. In a few cases fugitive greenhouse gas emissions through the water cycle were also provided. These data were augmented with other publicly available data and validated with participating utilities.

A summary of the raw data from each water service provider (water utility) surveyed is provided in *Appendix 1*. The data are aggregated to the 'city' level and presented in Table 1. Results of this study are dependent on these data.

As a component of the survey process, 'treatment' and 'transport' energy were defined (see *Definitions*). Despite this, separation of available data on a site-by-site basis was not practicable for all utilities and the separation process itself was problematic. Comparisons of treatment or pumping within or across utilities need to include consideration of the specific local context.

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

Discussions on energy-related greenhouse gas emissions in this report do not include offsets or sequestration, and hence greenhouse figures quoted in other reports may be lower. As fugitive emissions are not consistently measured or reported this report does not provide analysis on these emissions. The Water Services Association of Australia however is undertaking further research characterising fugitive emissions and developing improved methodologies to account for these emissions. This work is considered a high priority as decision makers rely on greenhouse gas estimates that cannot be derived solely from energy use data.

**Table 1 Energy and water use by city (2006/07)**

	Sydney	Melbourne <sup>1</sup>	Perth	Brisbane <sup>2</sup>	Gold Coast	Adelaide <sup>3</sup>	Auckland <sup>4</sup>
Population served	4 300 000	3 621 000	1 538 000	1 006 000	492 000	1 095 000	1 232 000
<b>Water supplied (GL)</b>							
Total	507	412	235	113	65	159	136
Residential water	315	257	170	61	40	112	83
Indoor water use (%)	65	84	53	–	–	–	–
Wastewater collected (GL) <sup>2</sup>	508	296	119	86	47	89	104
<b>Total energy (GJ)</b>							
<b>Water supply</b>							
Pumping	1 687 960	125 355	423 000	28 245	39 416	1 041 901	44 460
Treatment	186 009	12 860	409 000	246 337	9 234	55 418	56 749
<b>Wastewater</b>							
Pumping	119 916	459 713	92 800	39 726	50 030	32 064	42 697
Treatment	698 205	739 243	213 000	138 028	119 389	185 194	273 593
Other energy demand	250 838	131 728	162 700	49 070	39 461	123 240	23 157
Total energy demands <sup>8</sup>	2 942 929	1 468 900	1 300 500	501 406	257 530	1 437 817	430 504
GHG emissions for energy-related sources (k t CO <sub>2</sub> -e) <sup>5</sup>	774	302 <sup>6</sup>	313	138	75	392	31 <sup>7</sup>

1 Melbourne wastewater flows only include flows to Melbourne's two main wastewater treatment plants (Western and Eastern Treatment Plants at Werribee and Carrum respectively.)

2 Brisbane's population only includes the population immediately served by Brisbane Water. It does not include the people served by neighbouring local government who purchase bulk water from Brisbane Water; water supply treatment includes approximately 70% energy use for pumping of water at the Mt Crosby Water Treatment Plant.

3 Close to the completion of this report, energy use for water supply pumping for Adelaide was amended from 995 041 to 1 041 901 GJ. The results of this late change were traced through to Table 2 and Section 3.1.6, but were not translated through the balance of the report as the implication was perceived as relatively minor. This may account for small discrepancies.

4 Total energy figures for Auckland are derived by tripling figures reported by the retailer – Metrowater serves one third of Auckland's population) – then added to figures reported by the bulk water supplier (Watercare).

5 Greenhouse gas (GHG) amounts quoted are full fuel cycle (FFC; see Definitions and Appendix 2) and are as reported by water utilities surveyed in January 2008. Offsets are not accounted and therefore offsets or net emissions reported by others may be lower due to the affects of considering offsets or sequestration.

6 Melbourne GHG figures: Yarra Valley Water serves 42% of Melbourne population. Figures reported are scaled up by 2.4 to represent all retailers.

7 Auckland greenhouse gas emissions are only for bulk supplier (Watercare) as no data were available for the retail utility surveyed. Other energy demand includes offices, etc.

8 Energy was reported to CSIRO both as use and source supplied. There were some relatively minor discrepancies. In these cases CSIRO used the "use" data.

Source: All data are sourced from survey of utilities or as otherwise noted in Appendix 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 each city's commonalities and differences. 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 3 provides a comparison of energy intensities for water supply and wastewater disposal for the year 2006/07 which was the only year where detailed data were available. Energy intensities for water supply (the amount of energy needed to deliver water) ranged from 335 GJ/GL for Melbourne to 6901 GJ/GL for Adelaide. This wide disparity can be explained in part by extreme drought conditions and atypical water shortages requiring increased long-distance pumping for Adelaide and Sydney in 2006/07. In contrast, most of Melbourne's water supply was gravity fed from elevated catchment storages. Significant energy is required to lift water against gravity – typically needed for long distance water transport. In fact, Adelaide's figure of 6901 GJ/GL is more than half of the energy intensity of seawater desalination (approximately 13 000 GJ/GL)(Based on various estimates including Gardner et al. 2006).

For wastewater treatment and disposal, energy intensities ranged from 1610 GJ/GL (Sydney) to 4051 GJ/GL (Melbourne). Sydney discharges most of its wastewater directly to the ocean after primary treatment, while Melbourne needs to transport its secondary- and tertiary-treated wastewater relatively long distances over higher terrain before ocean disposal. On a per capita basis, Adelaide at 1313 MJ/(cap\*a) is the most energy-intensive supply per person, 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 supplied (GJ/GL)	3 696	335	2 431	748	3 540	6 901	744
Wastewater (GJ/GL)	1 610	4 051	2 069	3 605	2 570	2 469	3 041
Total water supplied							
kL/(cap*a)	118	114	112	132	153	145	110
L/(cap*d)	323	312	308	362	419	398	302
Residential water (L/(cap*d)) <sup>1</sup>	201	194	166	220	303	278	185
Indoor water use (L/(cap*d))	130	163	123 <sup>2</sup>	163 <sup>2</sup>	161	206 <sup>2</sup>	–
Total energy (MJ/(cap*a))	684	406	498	523	846	1 313	358

*1 Residential water use is strongly related to restriction levels and other factors that vary from year to year. Water consumption levels in 2006/07 were 18% lower for Brisbane and 10% lower for Melbourne than in 2005/06. Perth water consumption was approximately 5% higher than the preceding year. Longer-term analysis is necessary to identify trends and underlying causes.*

*2 Amount estimated assuming 74% of water use was for indoor purposes (the average of Sydney and Melbourne).*

*Source: Data are derived from Table 2 and are based on data provided by water utilities.*

### Sydney

Sydney Water and the Sydney Catchment Authority jointly manage Sydney's urban water supply system. 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 occurs sharply lifting Sydney's water supply

energy consumption. Sydney also has 14 water filtration and/or chlorination plants of which four are privately operated. The city 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 Sewage Treatment Plant (STP), requires all wastewater to be lifted 50 m to the top of the headland. The ocean outfalls require sufficient pressure to enable dispersal of the effluent. North Head STP accounts for approximately 15% of the total electricity consumption of Sydney Water Corporation.

In parallel with a number of other Australian cities, Sydney's population is steadily increasing while the amount of water required (both as a total and per person) has fallen significantly in direct response to demand management strategies. However, inherent physical limits to ongoing reductions in water supply in the face of continued population growth mean that population growth will be the dominant driver of increased future demand for water supplies. A notable trend for Sydney is increasing energy demand for water supply pumping – it more than doubled over a five-year period (738 755 GJ in 2002/03 to 1 687 960 GJ in 2006/07). In 2006/07, energy for supplying water represented approximately 70% of total water-related energy consumption, with energy for wastewater treatment making up most of the remainder. Energy requirements for both water treatment and wastewater pumping are relatively low.

The energy intensity of water supply in Sydney in 2006/07 was 3696 GJ/GL – an increase of 300% since 2000/01 when the energy intensity was 915 GJ/GL.

## Melbourne

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

The population served in Melbourne rose steadily over the period 2000/01 to 2006/07 increasing from 3.4 million to 3.6 million. However, over the same period, total water supplied declined from 505 GL in 2000/01 to 412 GL in 2006/07. Demand management and enhanced public awareness of decreasing rainfall patterns, declining inflows to storages and subsequent water restrictions have played a significant role in this reduction. The energy requirement for water supply fluctuated significantly during this period due to changes in the amount 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 ( $0.14 \times 10^6$  GJ versus  $1.2 \times 10^6$  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. In contrast, the city used 4051 GJ/GL to treat and dispose of its wastewater.

Electricity was the major source of energy (60%), with natural gas providing approximately 10% of this. The remaining 40% was from internal generation of electricity using biogas from the wastewater treatment plants. Hence only 60% of Melbourne's electrical power consumption was generated using fossil fuel sources such as 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<sub>2</sub>-e/GJ for the full fuel cycle).

## Perth

Perth has demonstrated a slow but steady increase in both population and volume of water supplied from 2001/02 to 2006/07. Until recently, water was supplied with a relatively consistent energy intensity of around 2000 GJ/GL. This jumped dramatically to 3540 GJ/GL when the desalination plant was commissioned in 2006. The dominant source of energy for Perth's water system is electricity ( $1.15 \times 10^6$  GJ), with a small amount (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 – 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 2570 GJ/GL is significantly lower than that for water supply at 3540 GJ/GL.

Electricity consumption currently dominates the production of greenhouse gases by the Water Corporation and this will continue as the volume of water provided by desalination increases. The Water Corporation is working to reduce the level of greenhouse gas emissions through a number of initiatives.

## Brisbane

Brisbane Water's energy use profile has declined despite a slow but steady (1.2%) increase in population. This is likely due to the declining volume of water demand 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 2431 GJ/GL, mainly due to the need to pump water to the Mt Crosby and North Pine treatment plants. This energy value for pumping is included with the total energy value 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 2069 GJ/GL for wastewater disposal and a contribution of approximately 40% of total energy requirements.

Most 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.

## Gold Coast

Data for the Gold Coast show that energy demands for this area has been gradually increasing while 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 treatment and pumping is 3605 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.

## Adelaide

The population supplied by SA Water and the supply volume have remained fairly steady between 2006 and 2008. However, the total power requirements for water supply depends significantly on the proportion of supply pumped from the Murray River at Mannum. In 2006/07, for example, the power requirements for pumping jumped to a high of 1 042 000 GJ as an extra 48 GL were pumped from the Murray River to provide extra storage during drought conditions. The energy demand for water supply pumping increased by 117% between 2005/06 and 2006/07 and this is reflected in the energy intensity

of water supply of 6901 GJ/GL in 2006/07. Electricity from coal- and gas-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 pumping and treatment at 217 258 GJ. This is largely due to a very low pumping energy requirement of only approximately 32 000 GJ/a (note: there is a 20 m fall between Adelaide city and Bolivar Wastewater Treatment Plant). A high proportion of the energy for wastewater treatment is generated in gas turbines fed either by biogas generated in the treatment plant or imported natural gas resulting in about 30% of the energy used in wastewater treatment coming from on-site generation sources. The energy intensity of wastewater in Adelaide (2469 GJ/GL) is low relative to other utilities. The use of biogas and natural gas further reduces the greenhouse gas footprint of wastewater.

## Auckland

Data for Auckland include data supplied by Watercare (the bulk supplier) and Metrowater (one of three retailers in the Auckland region). Metrowater supplies 34% of the population of greater Auckland. To obtain the full picture for Auckland the data from Metrowater were multiplied by a factor of three before being added to those of the bulk supplier. These data show a slow but steady growth in both population and volume of water supplied, while the amount of energy used in water supply remained 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 3041 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).

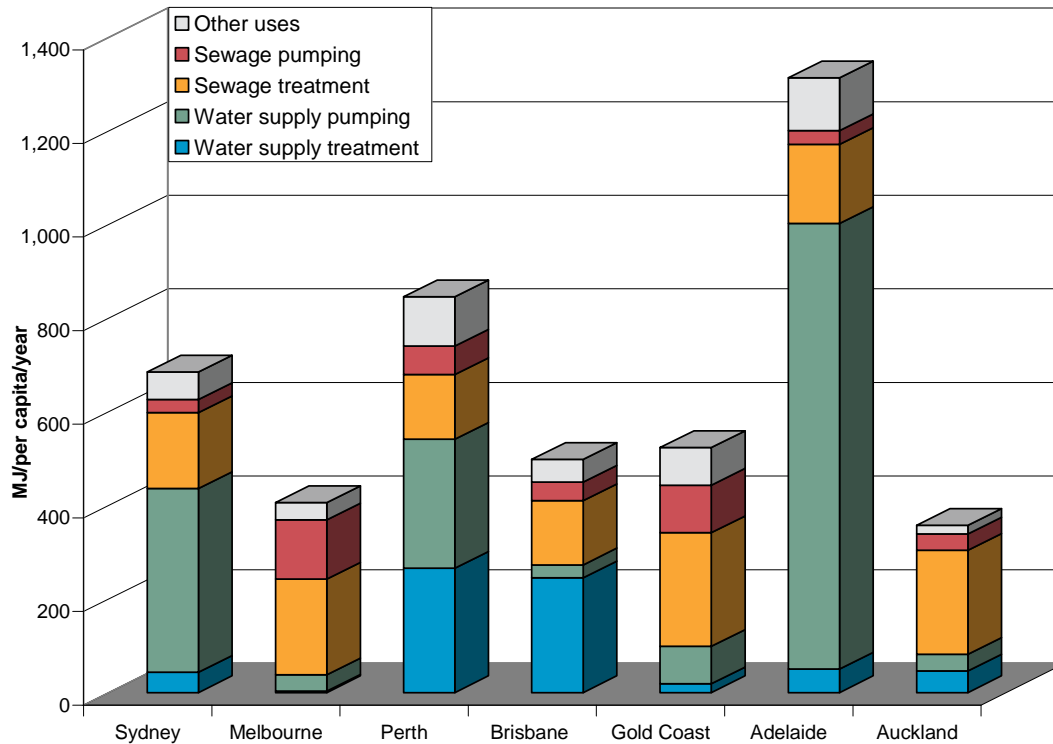
Electricity is the dominant source of energy, although significant quantities of natural gas are used for power generation at the wastewater treatment plants. About half of the total electricity consumption of 400 000 GJ is generated internally from biogas. As a consequence, the greenhouse gas footprint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

## Energy use comparison

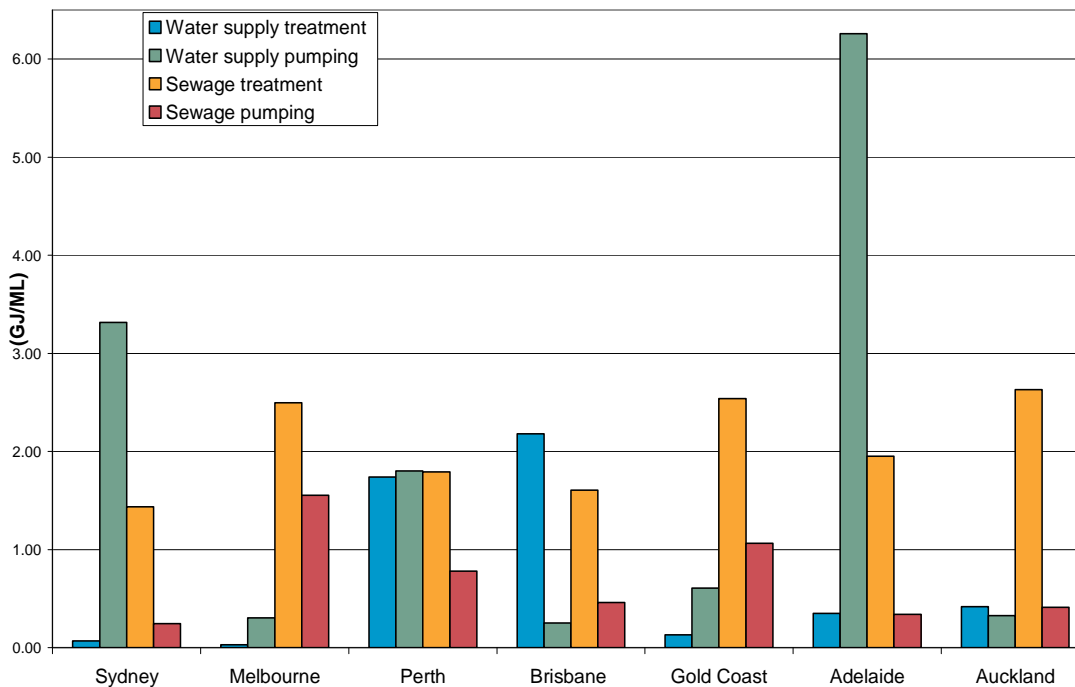
The energy consumption data for individual cities highlights that local circumstances and regulations have a significant impact on the energy use profile. **Figure 3** provides an aggregation of data for each city broken down into the individual demands for energy. In Adelaide, Perth and Sydney, water supply required the highest energy input for 2006/07; in Melbourne and the Gold Coast, wastewater disposal used larger amounts of energy. Cities such as Adelaide and Perth use significantly more energy per customer than cities such as Melbourne and Auckland. Specific local conditions need to be considered when interpreting the data. For example, in some systems, large amounts of energy are 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 4 provides an alternative perspective of the energy demands of each city. The high energy requirement for pumping for both Adelaide's and Sydney's water supplies and the relatively high energy use in tertiary wastewater treatment in Auckland and the Gold Coast are apparent. 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.

Since these figures relate to the financial year 2006/07, they reflect the local circumstances during that period. These 2006/07 data indicate very clearly that pumping water is extremely energy-intensive.



**Figure 3 Energy use for water and wastewater services (2006/07)**



**Figure 4 Energy use 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. the bars show total energy use, not net imported energy use). Water energy intensity is cited per volume of water supplied; 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.

## 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, a wide range of energy intensities reflect 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, some small plants (<1 ML/d) had 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 (including primary)	0.93 – 2.96	1.65
Tertiary (including secondary)	1.41 – 39.6	3.25

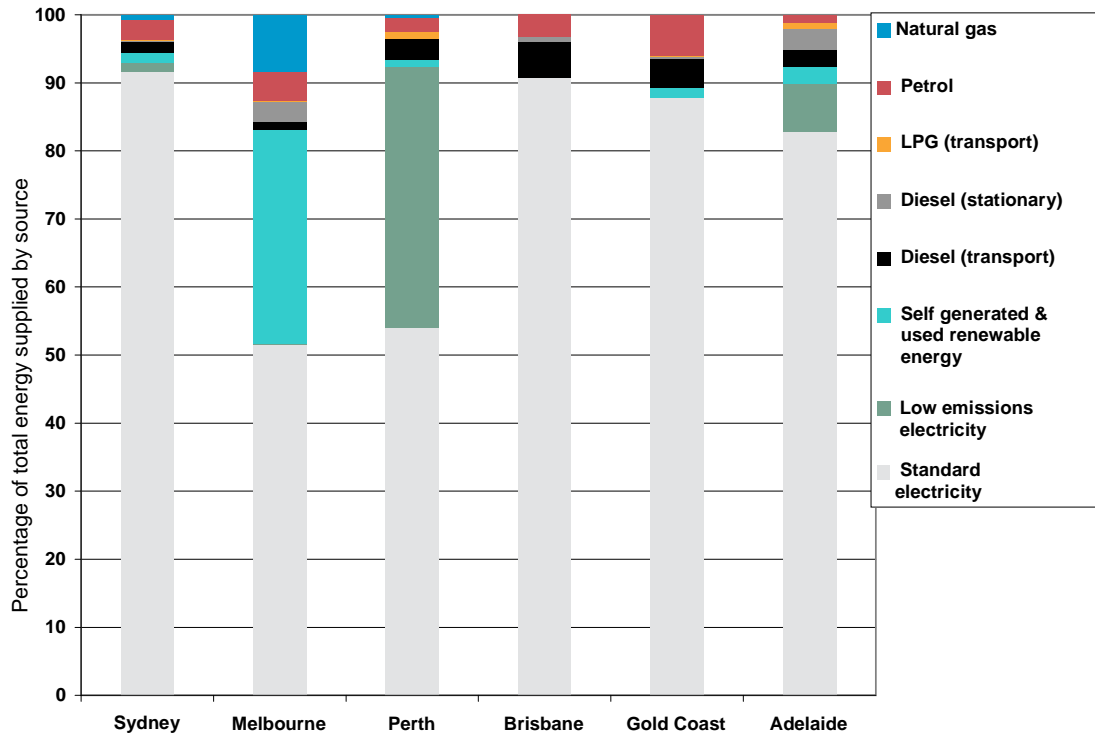
*Source: Data provided largely by Sydney Water and Brisbane Water. See Definitions for description of primary, secondary and tertiary treatment.*

## Greenhouse gas emissions

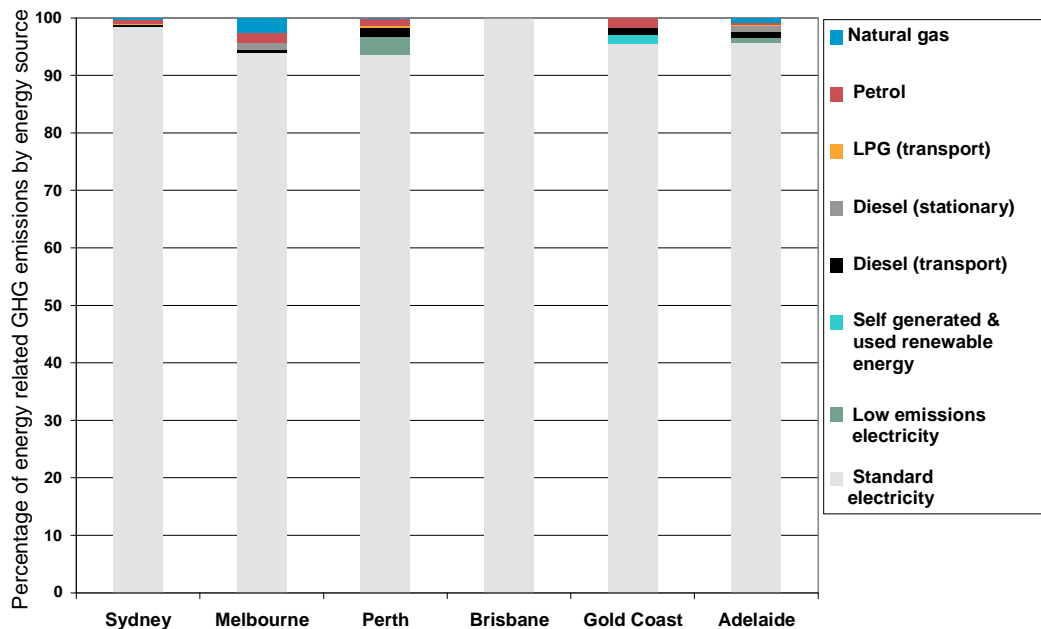
Energy-related greenhouse gas (GHG) emissions are the predominant source of GHG emissions from water utilities. However, non-energy-related sources, often referred to as 'fugitive emissions' (e.g. methane and nitrous oxide from wastewater treatment) also contribute to the GHG emissions of water utilities. 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 undertaking further research on fugitive emissions to develop better estimation methodologies.

Standard electricity, imported from the grid, is the main 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 data are available) with Sydney, Melbourne, Perth, Brisbane and Gold Coast sourcing over 90% of their reported energy-related emissions from standard electricity (Figure 6).



**Figure 5 Energy use by water utilities by source (2006/07)**



**Figure 6 Energy-related GHG from utilities by energy source (2006/07)**

*Notes: Transport fuels that have been reported in a volume (e.g. kL) have been converted to energy on basis of National Greenhouse Accounts Factors (Department of Climate Change 2008). The results for Sydney aggregate data from the Sydney Catchment Authority and Sydney Water. Melbourne data include Yarra Valley Water data scaled up by 2.4 to represent all retailers and whole-of-city scale plus Melbourne Water data.*

## Scope for reducing GHG emissions

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

- avoiding energy use where other options exist to 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)
- using wastes (e.g. biogas, biosolids, heat, pressure and flow such as 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 reducing fugitive emissions although these options are not addressed in this report. 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 reducing use of standard imported electricity.

Given that electricity is the dominant source of energy in the provision of urban water services in Australia and 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 when compared to other sources such as natural gas and diesel which 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 to produce either process heat or electricity that can be used in pumping, or treating supply or waste water. Melbourne is a good example of the beneficial use of biogas with some 40% of energy for wastewater treatment and disposal being generated in this way. 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 energy that may be used to pump water by recovering energy when water is flowing downhill. Wolff et al. (2004) detail a number of North American water pumping systems that are net producers of energy. Sydney Water is implementing a project in which 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 that cannot be offset through any associated biogas production. Consequently, transport of water over long distances 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 – to remove nutrients (e.g. nitrogen) that may cause eutrophication and water quality degradation in receiving waters – also creates a higher energy demand than secondary or primary treatment. In many cases, the high quality water produced may then be available for re-use.

While energy use by decentralised systems is assumed to be relatively low with perhaps the exception of backyard and industrial groundwater use in Perth, it is expected to increase as these systems are more widely adopted. Energy use associated with rainwater tanks can be high (Gardner et al. 2006) and is approximately 3600 MJ/ML (Marsden Jacob & Associates 2007) although this use is

significantly affected by local factors such as system design. Site-specific characteristics particularly influence the energy demand for pumping. Further analysis of the energy used by decentralised systems is warranted once more data are available.

While current urban water systems have significant infrastructure that combines black water with grey water in the sewers, some 90% of the nitrogen and 60% of the phosphorus is contained in the black water (Gray and Becker 2002). 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.<sup>1</sup> This could also facilitate simpler and safer water recycling operations, as the source for the recycled water would not be heavily contaminated with human waste.

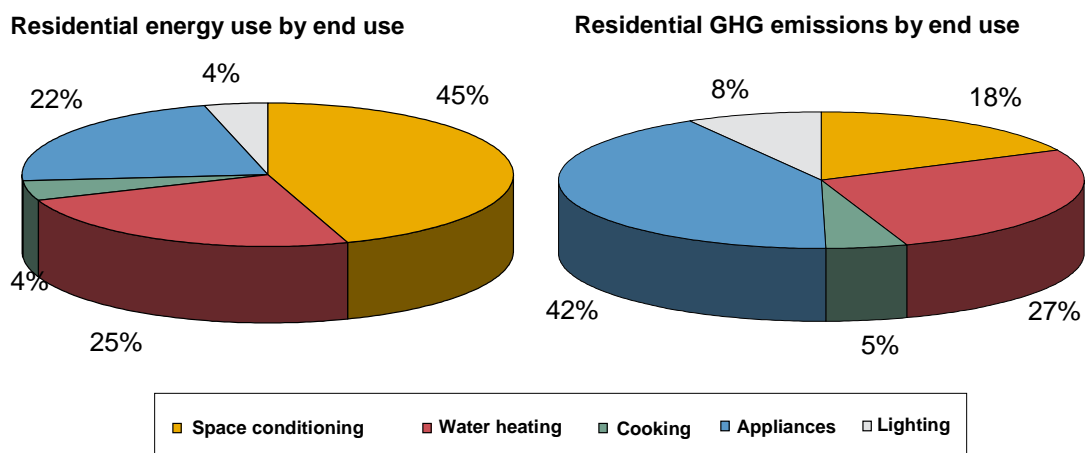
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<sup>1</sup> Natural gas is the key source of energy in the Haber-Bosch process for nitrogen fixation in the manufacture of nitrogenous fertilisers.

### 3. WATER USE AND ASSOCIATED ENERGY USE

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

Collection of data on energy consumption linked to residential hot water provision 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 data on energy used for heating water by industry. Figure 7 shows that water heating is responsible for 25% of residential energy demand and 27% GHG emissions in Australian households, excluding transport. 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.



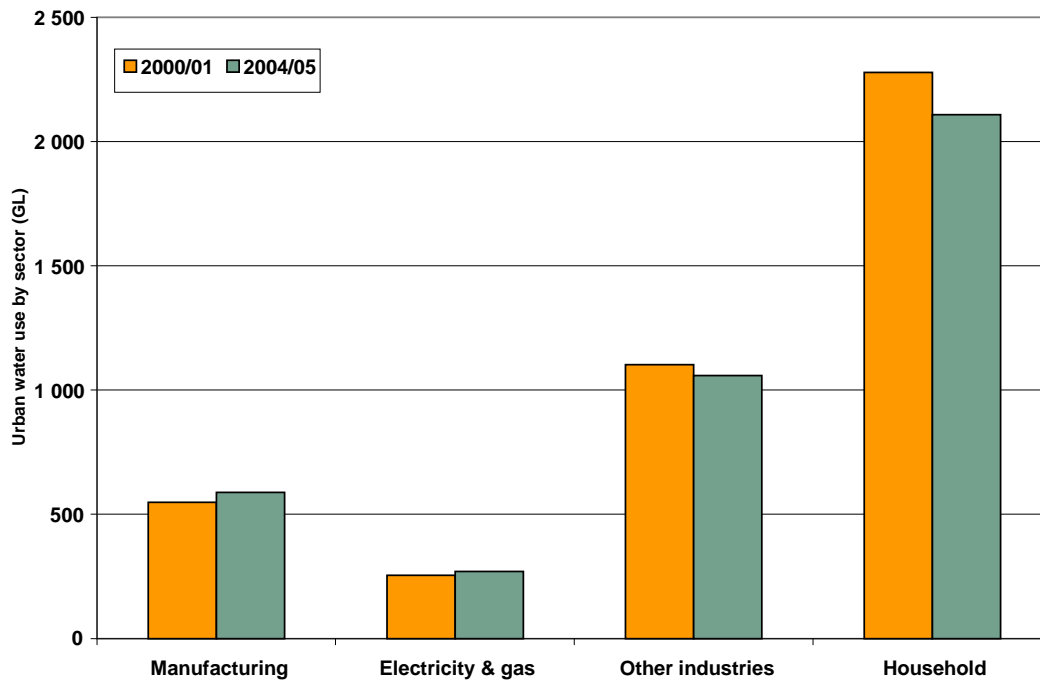
**Figure 7 Residential energy demand and GHG emissions end-use allocation**

Source: GW&A 2002

### Introduction

Households use significant amounts of energy to heat water. The greatest reductions in energy consumption in the urban water cycle can be achieved through increased water efficiency by end users (Wolff et al. 2004) in part because a reduction in urban water demand will reduce the 'upstream' energy required in sourcing, treating and pumping water to end users as well as the energy required 'downstream' to treat and discharge wastewater. However, the greatest impact on energy demand for a household is through reducing demand for water in energy-intensive end uses, in particular those requiring water heating. Residential end use of water can be responsible for substantially more greenhouse gas emissions than all upstream and downstream operations (Flower et al. 2007a). Strategies aimed at reducing energy consumption and greenhouse gas emissions in the urban water cycle will benefit from improvements in end-use water efficiency.

Figure 8 shows the urban water use by sector for the financial years 2000/01 and 2004/05. It 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 with an increased consumption of 7%; at the same time households also 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 water demand by households varies significantly between cities and 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, due in part to ongoing water restrictions in South East Queensland (Table 3). Perth had the greatest 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 as 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 was used outdoor purposes (ABS 2005). The impact of extended water restrictions is likely to have changed this breakdown with residential restrictions focused 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 was for outdoor use (Heinrich 2007).

## Residential and hot water energy use

### 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, although water-related energy is also used for filtering, pumping and heating swimming pools and spas (around 3.3% of household energy use (GW&A 2004)), followed by dishwashers and washing machines. This section focuses on energy associated with residential hot water services (HWS) that 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 mains 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).

### 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 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 analyses provided by utilities. Where this information was not available the proportion was derived from a mean of Sydney and Melbourne usage patterns (Perth was excluded as it was considered not representative of the 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/d 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.

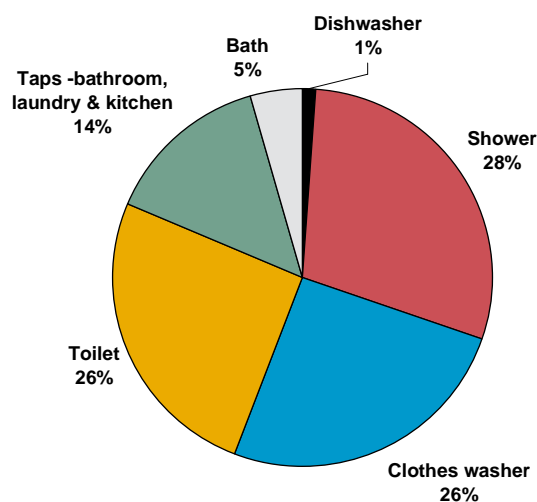
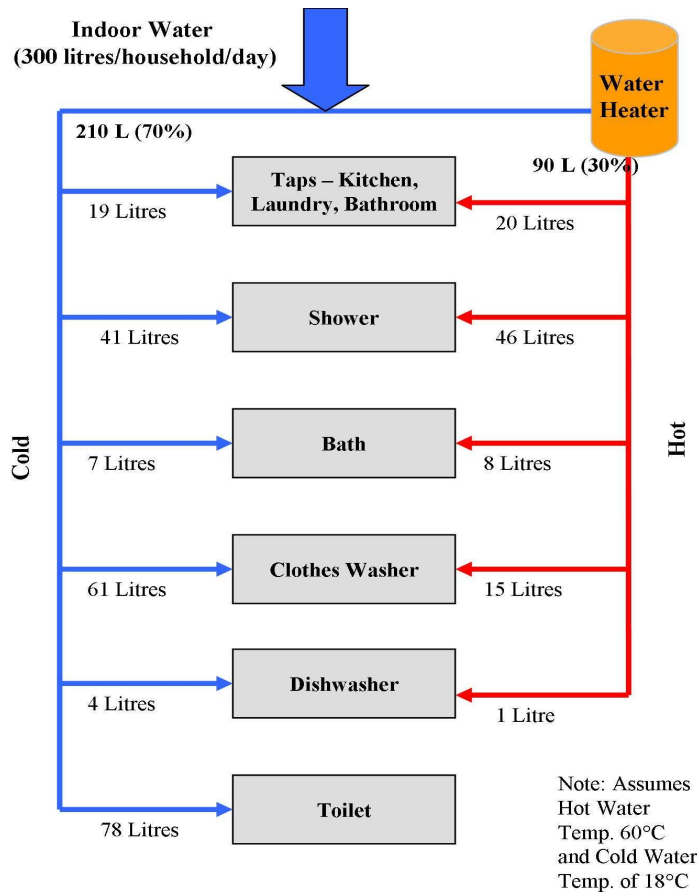


Figure 9 Indoor household water demand by end use for Australia

Source: GWA 2004



**Figure 10 Sample breakdown of indoor water end uses – hot and cold**

*Note: 300 L/HH/d indoor use is approximately equivalent to 160 L/(cap\*d) residential use for indoor and outdoor purposes. Adapted from GW&A 2004*

The energy required to heat the volume of hot water required is based on the 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 desired temperature; C is the specific heat for water (amount of heat per unit of mass required to raise temperature one degree Celsius = 4.186 J); 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 mains water temperature was based on the average monthly mains water temperature for Climate Zone 3 (Sydney and Brisbane) specified in AS/NZS 4234-2007 (Standards Australia 2007). The use of Climate Zone 3 means that for colder southern cities, such as Melbourne, where cold water temperature is lower, a higher energy usage could be expected. This contributes to the conservative nature of these estimates of energy demand for residential hot water heating.

The per capita values are scaled on the basis of population served. The estimate of energy use for residential hot water (Table 5) 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)**

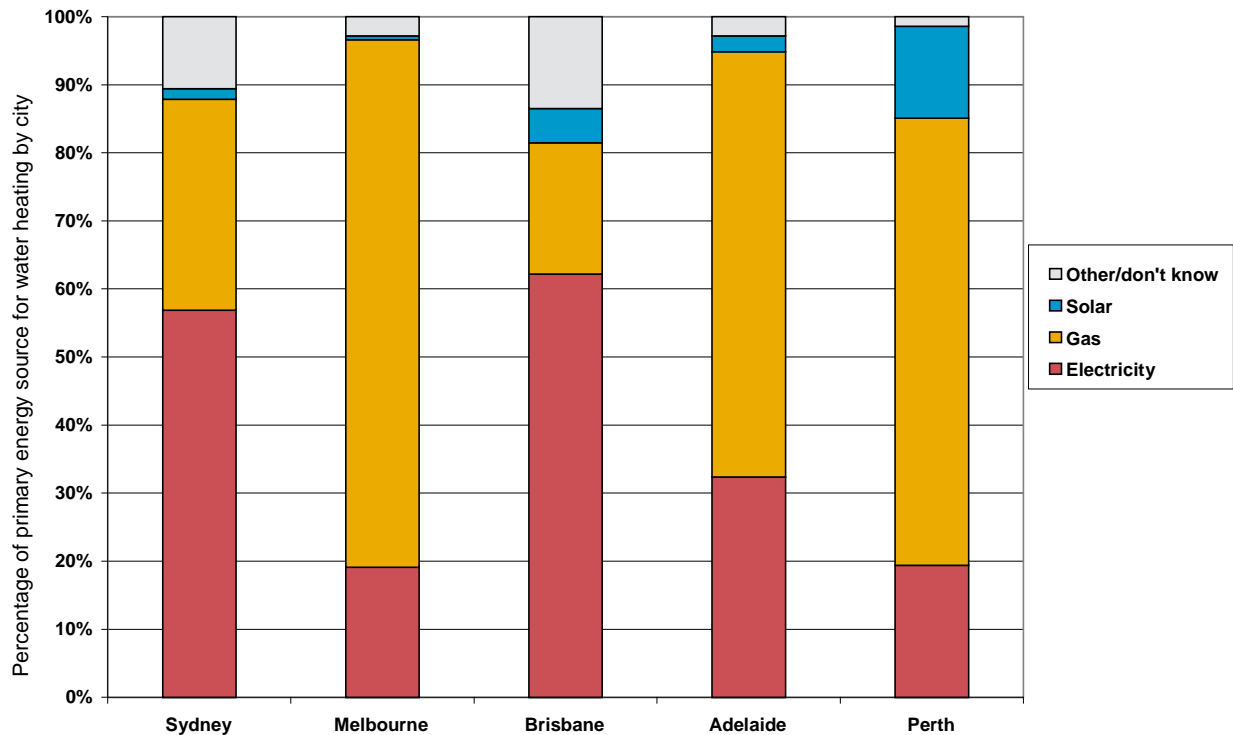
	Residential water supplied (GL/a)	Total indoor (GL/a)	Volume of residential hot water (GL/a)	Energy for residential hot water (PJ/a)
Sydney	315	205	82	14
Melbourne	257	216	86	15
Brisbane	61	45	18	3
Gold Coast	40	30	12	2
Perth	170	87	35	6
Adelaide	112	83	34	6
<b>Total</b>	<b>955</b>	<b>665</b>	<b>267</b>	<b>46</b>

These estimates were compared with figures from the Australian Standard 4552-2005 (gas-fired water heaters for hot water supply and/or central heating). This standard suggests a daily standard load of 37.7 MJ/HH, which is used in determining the energy rating of water-heating appliances and is assumed to apply at the higher end of household water use. This load was used to compare 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, they provide an idea of the energy going into residential water heating and indicate that figures for this project may underestimate energy use for residential water heating.

The fact that thermal efficiency was not considered in the estimates of water heating energy also influences the underestimation 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.

### **Influence of energy source for water heating on GHG emissions**

Figure 11 shows the primary energy source for water heating in Australian cities. It shows that in Melbourne most households (77%) use gas for water heating while Sydney 57% of households are reliant on 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<sub>2</sub>-e. In contrast gas storage systems account for around 35% of national energy use for residential water heating and around 12% of the GHG emissions (GW&A and Energy Strategies 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 Water heating sources used by households in Australia's major capital cities (2005)**

*Note: Estimates of GHG emissions from water heating within each state could not be sourced.*

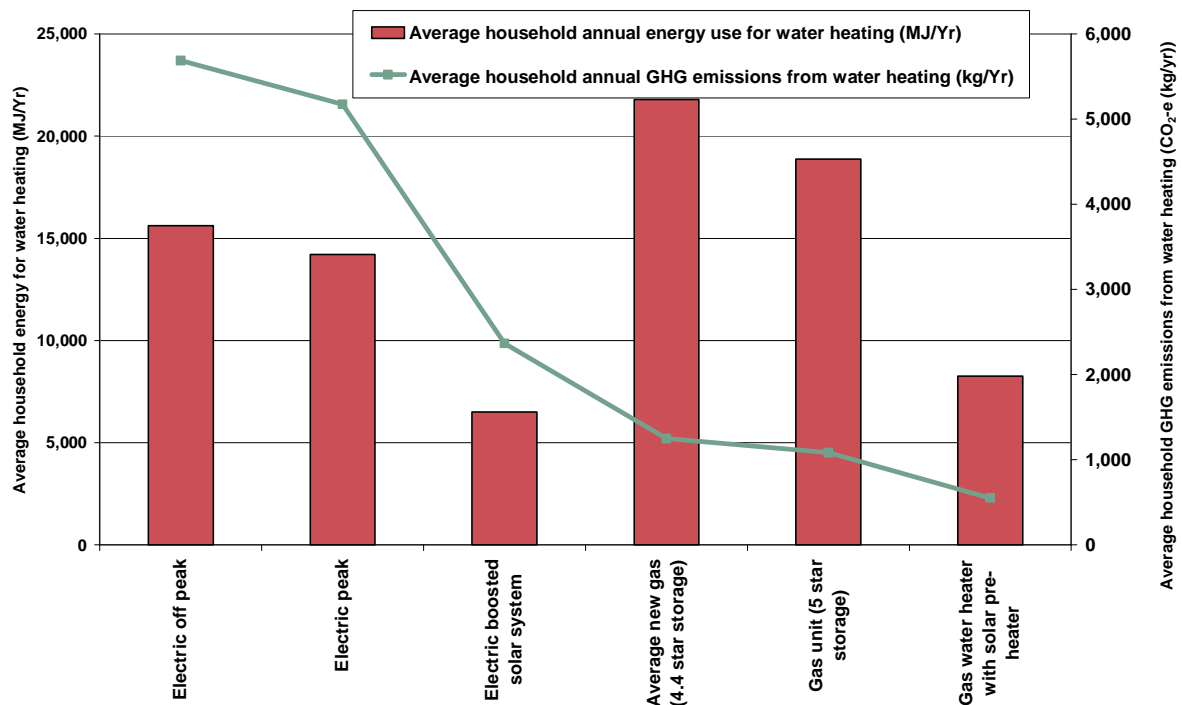
*Source: ABS 2005*

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 shows results from modelled scenarios, produced by Sustainability Victoria (pers. comm.) and 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:

- three-person household
- average daily hot water use of 178 litres (65 kL/a/HH)
- base annual energy load for household water heating of 12 213 MJ/a (based on the equation detailed in Section 0)
- GHG coefficients based on National Greenhouse Accounts Factors (Department of Climate Change 2008).

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. Figure 12 shows the estimated annual GHG emissions for different HWS in Melbourne by household size, showing that 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, explaining 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.

This analysis only considers the operational energy required to heat the water and does not consider the embodied energy of different hot water systems.



**Figure 12 Hot water system energy demand and GHG for water heating**

Source: Data from Sustainability Victoria May 2008 (assumes 178L/HH/d of hot water use).

**Table 5 GHG emissions (t/a) from various hot water systems (Melbourne)**

	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

## Demand management strategies

This section explores the impact of two demand management strategies on residential water demand for hot water, and associated energy and GHG emissions taking HWS type into consideration. 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 use scenario. Characteristics common to both scenarios were:

- three-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).

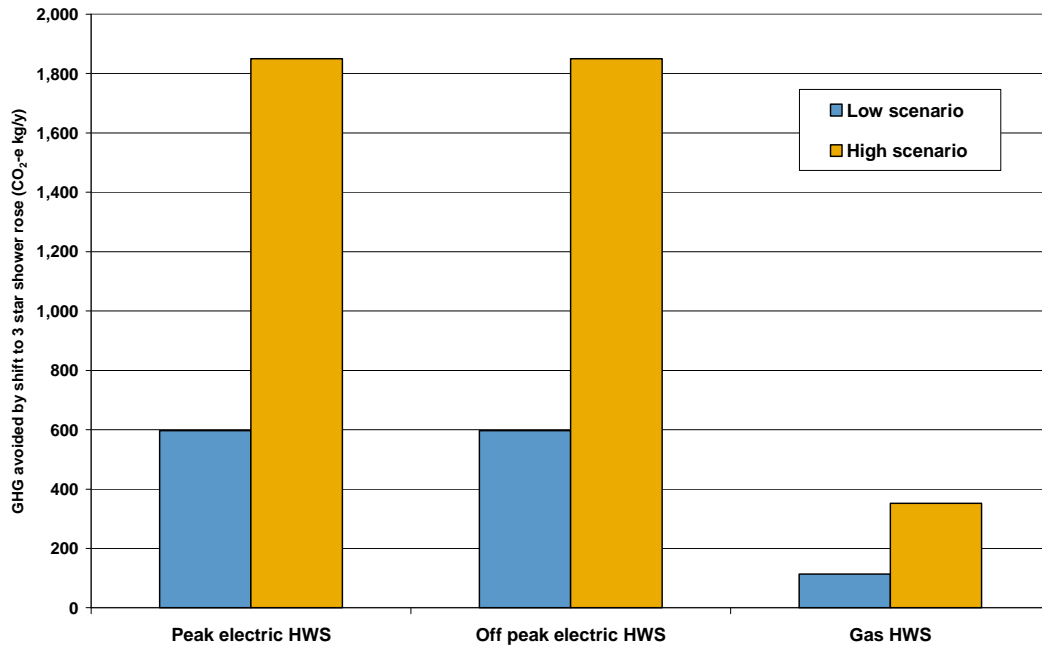
The WELS 3 Star rose is assumed to have an average flow rate of 8.1 L/minute. Table 6 characterises two scenarios – high water-use household and low-water use household. This table also shows the relative impacts on the hot water demand and associated energy for a shift to a 3 Star rated low flow shower rose. Figure 13 demonstrates the impact of this shift in terms of GHG emissions avoided that takes into consideration thermal efficiency of different systems. It 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 3-star shower rose**

	Low water use scenario	High water use scenario
Shower flow rate (L/min)	12	15
Average shower time (min)	4	7
Current shower water use (L/a)	47 304	103 478
Current hot water use (L/a)	26 280	57 487
Current energy demand for shower water heating (MJ/a)	4 950	10 829
Shower water use with 3-star shower rose (L/a)	31 930	55 878
Water saving with 3-star shower rose (L/a)	15 374	47 600
Hot water savings (L/a)	8 541	26 444
New energy demand for shower water heating with 3-star shower rose (MJ/a)	3 342	5 848
Energy savings (MJ/a) <sup>1</sup>	1 609	4 981

<sup>1</sup> Not considering HWS thermal efficiency

Data source: Sustainability Victoria May 2008



**Figure 13 Range of GHG savings per household through a new 3-star shower rose**

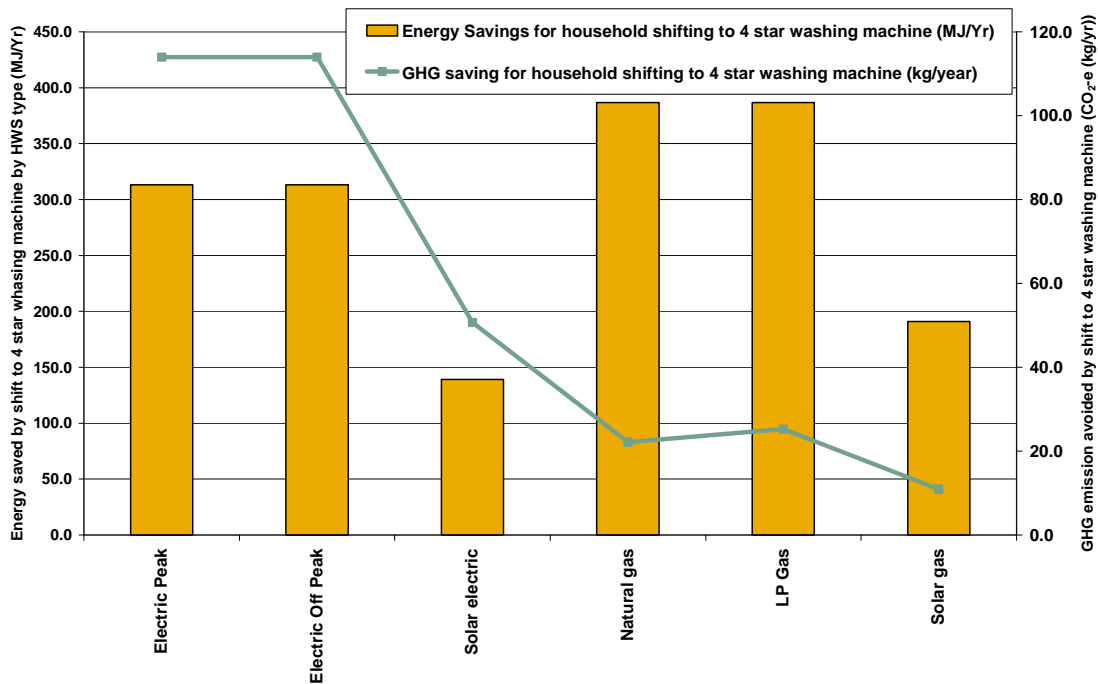
Data source: Sustainability Victoria May 2008

The second demand management strategy explored is a shift to a 4-star front loading washing machine from a WELS 2-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/a electrical consumption by 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-star top loading 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-star rating)	Front loading clothes washer (6.5 kg, 4-star rating)
Water consumption (L/cycle)	102	62
Comparative energy consumption (kWh/a)	474	220
Estimated water heating energy (kWh/a)	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 by shifting from 2-star to 4-star washing machine**

Data Source: Sustainability Victoria May 2008

## Industrial and other uses of water

Very little data are 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' (GW&A and Energy Strategies 2002) shows that, in the industrial sector, water heating for amenity (97 000 t CO<sub>2-e</sub>) is a relatively minor contributor of GHG while industrial boilers (18 538 000 t CO<sub>2-e</sub>) is a major contributor of GHG and comparable to residential hot water energy use nationally (18 815 t CO<sub>2-e</sub>).

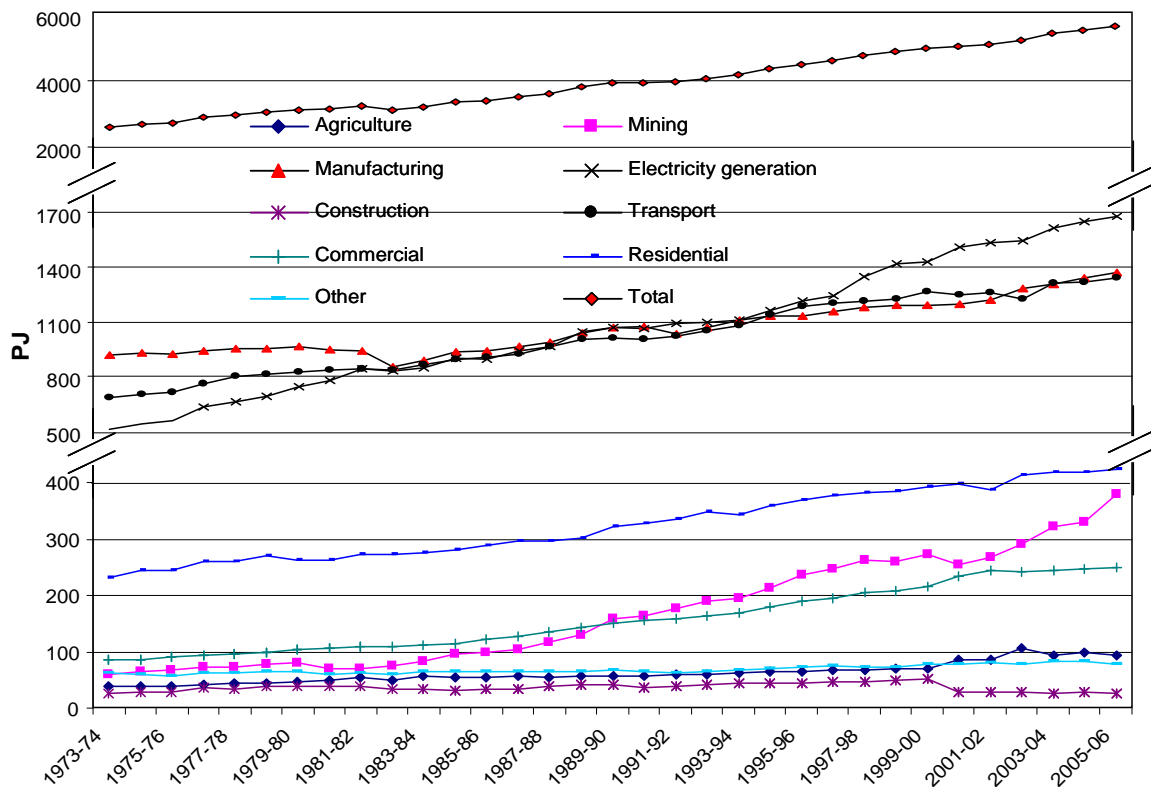
Significant new data would be necessary to better estimate energy use associated with non-residential end use. These data would need to include improved attribution of energy use to water end use and processes within industry. It is possible some process data from life cycle analysis of different industry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

## 4. URBAN SYSTEMS

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

### Energy use

Population growth and an increasing standard of living are driving the growth of energy consumption in Australia. . 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). The Australian Bureau of Agricultural and Resource Economics (ABARE 2006) estimates, Australia's energy consumption is projected to grow by 2% a year, from 5593 PJ in 2004 to 6311 PJ in 2010. Electricity generation, transport and manufacturing use the most energy. 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. The residential and commercial sectors used 52% (335.5 PJ) of electricity generated in 2001. Residential energy consumption has nearly doubled since 1973/74.

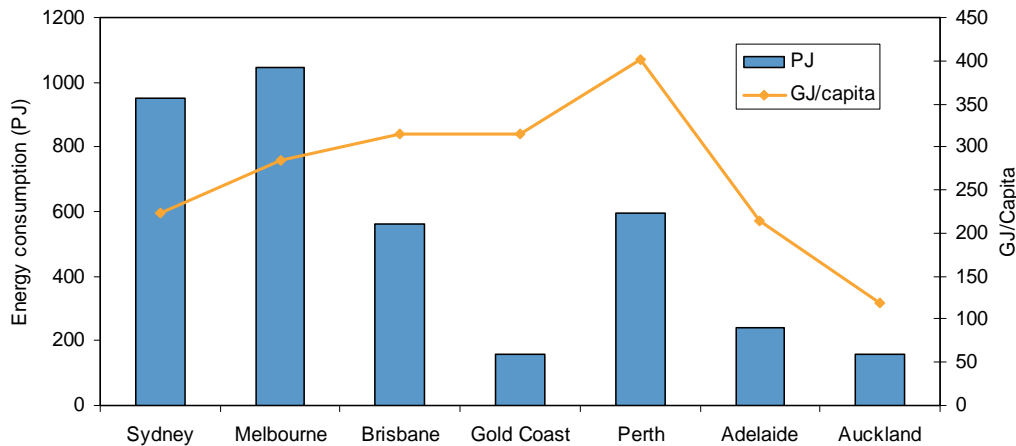


**Figure 15 Energy consumption in Australia by sector (ABARE 2006)**

Total energy consumption comprises all energy used for water, wastewater and drainage, including agriculture, mining, manufacturing & construction, transport, commercial & services (which was classified into Australian and New Zealand Standard Industry Classification (ANZSIC 6700 storage industries). This includes a wide range of energy users outside the immediate boundaries of the areas supplied by water utilities. However it is argued that the demand of energy for these uses is primarily to meet the needs of urban residents.

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 each city. The pro-rata estimates are approximations of 'urban systems energy use'. However this approach assumes that individuals in each city 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 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.

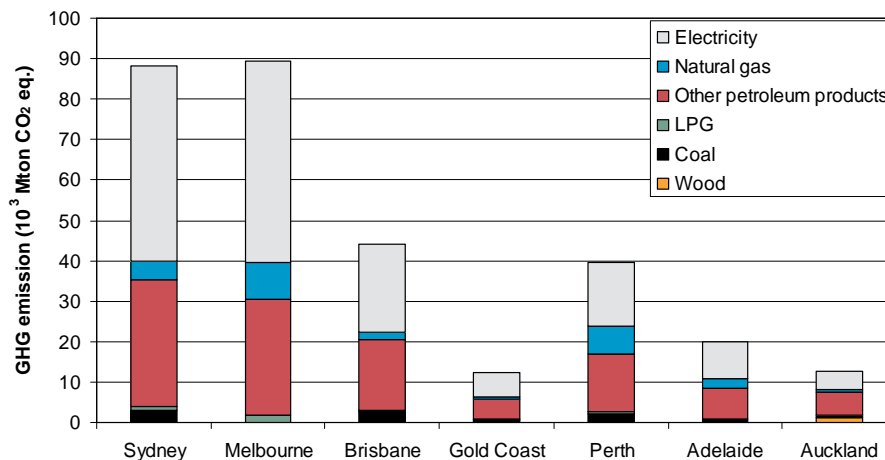


**Figure 16 Total energy consumption by city and demand per capita (2006/07)**

Perth has the highest per-capita demand for energy (around 400 GJ/cap/a) however this may be skewed by high energy use outside the Perth area (e.g. mining areas) as the state is responsible for more than 30 % of Australia’s exports. Auckland has around one-quarter of the energy use of Perth and between one-third and one-half the per-capita use 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.

## Greenhouse gas emissions

Data from ABARE’s Australian Energy Consumption database indicates that the cities studied in this report emit up to 90 Gt of greenhouse gases (ranging from approximately 90 Gt for Sydney and Melbourne, down to approximately 12 Gt for Auckland). Electricity use (50% of total emissions) and petroleum products (40%) comprise most GHG emissions (Figure 17). When compared to these figures, the energy-related GHG emissions associated with water services provision (generally less than 1 000 000 t CO<sub>2</sub>-e per city) are relatively insignificant.



**Figure 17 GHG emissions by final energy consumption for cities (based on 2005 data)**

## 5. ENERGY USE BASE CASE AND PROJECTIONS

### Energy use base case

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

- energy use by water utilities in 2006/07 ranged from 0.1% (Melbourne, Brisbane and Gold Coast) to 0.5% (Adelaide) of total urban systems with a national average of 0.2%
- residential hot water ranges from 0.5% of total urban systems energy use (Brisbane) to 2.5% (Adelaide)
- energy use by water utilities as a percentage of energy use for residential water heating ranges from a low of 9% in Melbourne (where the water system uses relatively little energy) through to 21% in Adelaide.

Where the percentage of utility energy use to residential hot water energy use (calculated as the ratio of utility to residential multiplied by percent) is lower, the energy-related benefits from focusing on managing indoor hot water demand rather than managing water utility energy use are greater. This is separate from greenhouse gas benefits which require consideration of the efficiency of the water heating appliance and the associated energy source.

**Table 8 Energy use for utilities, residential hot water and total urban system (2006/07)**

	Energy use (PJ/a)			Energy (% of urban system)		Utility energy use as % of hot water energy use (W/Rx100%) (%)	Energy use (MJ/capita)		
	Water utility (W)	Res hot water (R)	Urban system (T)	Water utility (W/Tx100%) (%)	Res hot water (R/T) (%)		Water utility	Res hot water	Urban system
Sydney	2.7	14	950	0.3	1.5	19	626	3 260	223 000
Melbourne	1.3	15	1 050	0.1	1.4	9	369	4 140	284 000
Brisbane	0.5	3	560	0.1	0.5	15	450	2 980	314 000
Gold Coast	0.2	2	160	0.1	1.3	11	442	4 070	314 000
Perth	1.1	6	600	0.2	1.0	19	741	3 910	402 000
Adelaide	1.3	6	240	0.5	2.5	21	1 157	5 480	214 000
Total	7.1	46	3560	–	–	–	–	–	–
Weighted Averages	–	–	–	0.2	134	15	590	3818	277 000

*Note: Total urban system (T) is a per-capita estimate of energy use by the state in which the capital is located. This includes energy use for agriculture, mining and transport.*

The relatively low percentage of energy use by water utilities compared to energy use in residential water heating indicates that a 15% saving in residential end use of hot water (e.g. through demand management or altered consumer behaviour) has the potential to more than offset current energy use by water utilities. This surprises many and some recent authors (Beal et al. 2008) have noted much higher percentages (e.g. 50%) at Silva Park in Brisbane. However the Silva Park development is atypical in Australia as it used decentralised water supply options (rainwater tanks, greywater re-use) that require 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 as served by water utilities, were inconsistent with ABS data (1 786 079 and 1 134 579 for Brisbane and Adelaide respectively). This variation is probably associated with the use of different boundaries within which to characterise the population. It was accounted for by comparing per-capita data 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.

## **Future projections of energy use**

A number of 'what if' projections were considered to illustrate the upper and lower bounds of future energy use of supply and waste water flows, and domestic water heating of an aggregated demand and supply for the urban centres of Sydney, Melbourne, Brisbane, Gold Coast, Perth and Adelaide. At the time of analysis, comparable datasets were not available for Auckland which also represented quite a distinct (low energy) system. Consequently it was not analysed for future estimates.

Projecting future energy use can 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 for 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.

## **Population, water demand, water supply and wastewater flows**

The collective Australian population that will be serviced by the utilities in 2030 is estimated to be 15.8 million; 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 the water utilities and given that in 2006-07, with most cities under significant water restrictions, national residential water use was 228 L/(cap\*d) (WSAA 2008).

The three residential water demands reflect the upper, middle and the lower values of current practice. Lower water demand (150 L/(cap\*d)) carries many social assumptions and is based on current practice in South East Queensland and other regions facing water restrictions. It may not be socially acceptable (or maintained) over the long term. However, it does provide a lower limit 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 residential use 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 although 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 a negligible additional demand (at 150 L/(cap\*d)) to 1388 GL/a (for 300 L/(cap\*d)).

**Table 9 Water flows at three levels of residential water consumption (2030)**

Residential demand (L/(cap*d))	Total residential water supplied (GL/a)	Total residential and commercial water supplied (GL/a)	Current water supply capacity (GL/a)	Additional water supply required (GL/a)	Indoor water use (GL/a)	Current wastewater collected (residential and commercial) (GL/a)	Additional wastewater collected (GL/a)
300	1 734	2 890	1 502	1 388	1 040	901	833
225	1 300	2 167	1 502	665	780	901	399
150	867	1 445	1 502	-57	520	901	-34

To meet the predicted future water demand, two water supply source mixes were considered. The first was 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 re-use, 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% re-use 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 that perhaps sets an upper bound for energy demand excluding long-distance water transfer proposals.

### Energy intensities – water and wastewater treatment and pumping

Estimation of 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 supplies was estimated using the energy intensities shown in Table 10.

Energy projections are very sensitive to the technologies used. Upper and lower estimates for energy intensities for technologies such as desalination and wastewater re-use are provided where possible. However, energy intensities for these technologies have changed dramatically over the past decade and are very dependent on factors such as input water quality and processing method.

**Table 10 Assumptions used in forecasting energy use (2030)**

Treatment or pumping component	Lower energy intensity (GJ/ML)	Upper energy intensity (GJ/ML)	Energy intensity used for projections (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 re-use	3.6	5.4	4.5
Reverse osmosis on sea water	12.6	14.4	13.5
Pumping energy for re-use	3.6	7.2	5.4
Pumping energy for desalination	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 wastewater treatment would follow current practice, which was based on the *National Performance Report 2006-2007 urban water utilities* (WSAA 2008). This gave 20% primary, 25% secondary and 55% tertiary wastewater treatment based upon the total volume treated for all utilities in the report. Although secondary and tertiary treatment may increase in many areas it was assumed to be partly balanced by large centres such as Sydney that will continue to use primary treatment and deep water ocean outfalls.

The energy intensity for 'reverse osmosis on treated wastewater for re-use' 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 re-use. This assumption does not evaluate the capacity for various urban centres to supply the required amount of tertiary treated wastewater for re-use. For example, Sydney Water uses tertiary treatment for only 22% of its wastewater (WSAA 2008).

Pumping energy for supply and waste water was calculated as a weighted average using data for pumping energy, water and wastewater volumes and population (see Table 2). The weighted average captures current pumping energy for city populations and geography. Although applicable at a national level, a wide range of pumping energy is used in particular regions of Australia and may change over time with the growth and spread of cities. Pumping energy for desalination and re-use was considered separately.

## Energy use for residential hot water use

The methodology articulated in Section 4 was used to estimate energy use associated with residential water heating in 2030 and assuming a total city population of 15 883 000. Key assumptions and estimated energy use are presented in Table 12.

**Table 11 Estimated energy needs at three levels of indoor water use (2030)**

Residential water supplied (L/(cap*d))	Indoor water use L/(cap*d)	Main indoor end uses				Energy use (PJ/a)
		Clothes washer (L/(cap*d))	Shower (L/(cap*d))	Bath (L/(cap*d))	Toilet (L/(cap*d))	
300	195	51	57	10	51	80
225	167	43	48	8	43	68
150	128	33	37	6	33	52

## Energy projections

The following tables provide a summary of the energy projections associated with differing water supply option to 2030.

**Table 12 Estimated additional energy needs for various water supply options (2030)**

Residential water use L/(cap*d)	Conceptual sources for providing additional supply (GL/a)			Estimated additional energy requirements in 2030 (PJ/a)				
	Desalination	Re-use	Surface sources	Water treatment	Water pumping	Wastewater treatment	Wastewater pumping	Total (PJ/a)
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
150		Nil				Nil		

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

Estimates for future energy use of total urban systems were derived as a linear projection of the Australian Bureau of Agricultural and Resource Economics data on expected population growth. Future estimates for total energy use by utilities, for heating residential water and for urban systems under the three scenarios described above were assessed (Table 13).

**Table 13 Energy required by utilities, for residential hot water and total urban system (2030)**

Residential water consumption and additional water source	Energy use (PJ/a)			Energy (% of urban system)		Utility energy use as % energy use in heating residential water (%)	Energy use (MJ/capita)	
	Water utility (W)	Res hot water (R)	Urban system (T)	Water utility (=W/Tx100%)	Res hot water (=R/Tx100%)		Water utility	Res hot water
300 L/p/d-mix	26			0.5	1.6	33	1 660	5 060
300 L/p/d-desal	36	80		0.7		45	2 290	5 060
225 L/p/d-mix	16		5 002	0.3	1.4	24	1 030	4 300
225 L/p/d-desal	21	68		0.4		31	1 320	4 300
150 L/p/d	7	52		0.1	1.0	13	440	3 290

Note: For all scenarios, 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. Estimates for hot water energy demand are based on the methodology outlined in Section 3.2.2, 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 indoors
- the amount of water going to each end use decreases proportionally with the total demand – assuming that the 150 L/(cap\*d) residential use would be achieved through increased uptake of highly efficient appliances.

Total urban systems energy use in 2030 is based on forecasts outlined in Appendix 3 and is approximately 317,000 MJ/capita. No scenarios were considered to estimate the potential range of this energy use.

This analysis shows that:

- If 100% of new water supplies to 2030 is 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 PJ (approximately a 400% increase above baseline). This would represent approximately 0.7% of the energy use of the total urban system in 2030.
- If a mix of water sources is 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 energy use of the total urban system in 2030.
- If water consumption is constrained to 225 L/(cap\*d), if provided entirely by desalination or by a mix of desalination, re-use and surface sources, energy use for water provision increases to 21 and 16 PJ/a, respectively (0.4% and 0.3% of total urban system respectively).
- If water consumption is constrained to 150 L/(cap\*d), energy use by water utilities would remain approximately the same as in 2006/07 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 the 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 energy and water use in Melbourne through to 2045 (Kenway et al. 2008a; Kenway et al. 2008). However it is again stressed that local conditions in each system will dictate actual energy requirements and the viability of any particular

solution. Importantly, if water consumption can be constrained to 150 L/(cap\*d) residential use and that level of use can still provide for the services that the community expects and/or needs, then minimal additional energy would be required to provide supply and waste water services. A significant policy imperative deriving from this analysis is that focusing efforts on energy-efficient hot water production has significantly greater scope for lower energy use than can be derived from focusing on urban water systems energy in isolation.

This analysis has not considered solar hot water systems due to data limitations. Future work should consider the potential for solar hot water systems to reduce the GHG emissions associated with residential water heating.

## 6. EMBODIED ENERGY

This report focused 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 chlorination. 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 data from life-cycle analyses of urban water systems and found that greenhouse gas emissions associated with the pre- and post-operational stages of urban water infrastructure are relatively insignificant compared to operational GHG emissions (Flower et al. 2007a; Flower et al. 2007b). This trend, if true, is quite different to the pattern for buildings. For example Tucker et al. (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.

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 atmospheric greenhouse gases which are predicted to result in anthropogenic changes to the global climate. In order to reduce greenhouse gas emissions, a more comprehensive analysis of energy consumption in the built environment, including embodied energy is needed (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 supply and waste water services this involves assessing the overall expenditure of energy required to extract the raw material, manufacture products and maintain the pipe material. A secondary aim is to establish the embodied energy required to install and operate the pipe over its whole life cycle. An important consideration in terms of embodied energy over the total life cycle of the pipe is its expected service life.

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 these products can be estimated; but such estimation needs knowledge of the energy source used in the manufacturing process.

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 in Adelaide. Table 14 presents the annual energy consumption and corresponding CO<sub>2</sub> residential emissions in Adelaide City<sup>2</sup> in 2001. This enables the relative importance of embodied energy consumption and CO<sub>2</sub> emissions of components of the city to be presented. This analysis demonstrated that the supply and waste water systems were responsible for approximately 6% of the total annualised *embodied* energy and associated GHG emissions in the residential environment.

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<sup>2</sup> Adelaide City is a part of Adelaide

**Table 14 Annual embodied energy consumption in Adelaide City<sup>1</sup> (2001)**

Embodied energy (EE)	Total energy consumption (GJ)	Total GHG emissions (t CO <sub>2</sub> -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
<b>Total</b>	<b>6 391</b>	<b>441.0</b>
Average EE (or CO <sub>2</sub> -e) per capita	22	1.5
Average EE (or CO <sub>2</sub> -e) per household	39	2.7

<sup>1</sup> Adelaide City is a part of Adelaide

Source: Modified figures from Troy et al. 2003

## Energy embodied in common water assets

Basic factors that influence the embodied energy of water and wastewater piping systems are:

- pipe size – the bigger the pipe the more embodied energy
- amount of materials used – more materials equals a higher embodied energy
- pipes produced with significant recycled material – these materials usually have a lower overall embodied energy
- embodied energy coefficient of pipe material type – the lower the coefficient the lower the embodied energy
- durability of piping systems – more durable systems have a longer life expectancy; less repair and replacement leads to lower embodied energy over the life cycle of the system and
- maintenance of piping systems – appropriate maintenance can extend the life of the system, reducing embodied energy over its life cycle.

Embodied energy coefficients are usually expressed in gigajoules (or megajoules) per unit of mass. For supply and waste water pipes, the embodied energy coefficient is expressed in joules per linear metre rather than units of energy per unit of mass as this will significantly affect any 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 units of energy per unit of length then PVC outperforms ductile iron.

Plastic piping has significant advantages in terms of embodied energy due to the lighter weight per lineal metre (Ambrose et al. 2002). 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. The embodied energy in PVC pipes (PVC-M and PVC-0) of 300 mm nominal diameter ranged from 1358 MJ/m to 2041 MJ/m, and for PE (80B and PE100) pipes of similar diameter was approximately 2000 MJ/m. Ductile iron has approximately 40 MJ/kg material and PVC approximately 75-90 MJ/kg (Ambrose et al 2002).

Pullen (1999) estimated the embodied energies in infrastructure for water supply, wastewater and stormwater services were 0.7, 2.4, and 1.6 GJ/HH/a, respectively, in an Adelaide suburb. The comparison of conventional centralised water supply approaches with on-site collection and storage indicates that on-site capture and storage can have lower energy consumption in areas with reliable rainfall. 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) and showed that embodied energy can vary depending on the size and material type. The reinforced concrete tank has more than twice the embodied energy of the similar sized PVC lined steel tank.

**Table 15 Embodied energy of water storage tanks**

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

Source: Pullen 1999

Domestic energy consumption in Sydney was estimated to be 19 GJ/cap in 1970 (Kalma et al. 1972) and 13 GJ/cap in 1976 (Newman 1982). Since 1970, this figure has almost doubled to about 35 GJ/(cap\*a) (Lenzen et al. 2004). This difference was because Lenzen's (2004) research considered indirect energy consumption that was not considered in the earlier studies.

## 7. CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

The following conclusions can be made from these analyses and our current knowledge of water systems.

#### Energy use by utilities and water service providers

- Energy use by water utilities in Sydney, Melbourne, Perth, Brisbane, Gold Coast and Adelaide in 2006/07 was 7.1 PJ and met the needs of 12.048 million people (590 MJ/(cap\*a)). This energy use comprised 0.2% of total energy use by urban systems.
- Energy use by Auckland water utilities comprised 0.43 PJ and met the needs of 1.232 million people (349 MJ/cap\*a).
- Energy requirements for water supply and wastewater disposal vary significantly across different cities (Table 3). Most variation is able to be explained by the relative per capita use of water, pumping, and water and wastewater treatment requirements.
- Sourcing recycled water and desalinated water closer to the point of use may require less energy than pumping water from remote areas.
- If tertiary treatment of wastewater is required, then re-use opportunities are more favourable from an energy perspective, assuming energy needs for pumping after treatment are not overly high. This is because most high-quality re-use options require tertiary or equivalent treatment prior to membrane treatment or reverse osmosis.
- Efforts to minimise fuel-related greenhouse gas emissions from water service operations need to focus attention on minimising the use of imported electricity. Internal energy sources, such as biogas, can reduce the use of the more greenhouse-intensive coal-based electricity.
- Generally little information is available regarding the energy use of decentralised systems (e.g. rainwater tanks, backyard bores).

#### Hot water energy use

- Energy used for residential water heating in the cities studied in this report was estimated as at least 46 PJ in 2006/07 the 12.048 million people living in them. This is over six times the energy use of water utilities and 1.3% of total urban systems' energy use.
- A 15% reduction in residential hot water use could completely offset the total energy use by water utilities in 2006/07.
- Non-residential use of energy for water heating (e.g. for commercial and industrial uses) was not able to be estimated although it is expected to be of similar magnitude to residential energy use for water heating.

#### Greenhouse gas emissions

- Utilities rely on electricity generated from GHG-intensive fuels (brown and black coal) for approximately 90% of their total energy needs. A shift to cleaner energy sources, such as electricity generated from natural gas, would significantly reduce greenhouse gas emissions from fuel use in the water sector.

- In the case of water heating, the link between energy use and greenhouse gas emissions is not a linear correlation but is affected by appliance stock (which affects thermal efficiency and losses) and energy sources. Consequently additional analyses would be necessary to characterise greenhouse gas emissions (as opposed to energy consumption) from implementation of alternative policy options.
- Relatively little data exists for fugitive greenhouse gas emissions in the water cycle. Collection and analysis of such data are warranted.

## Future trends

- If national water consumption could be constrained to 150 L/(cap\*d) residential use then minimal additional energy use would be required for urban water provision to 2030. This is because these lower per capita consumption levels mean that total annual water consumption would be comparable to 2006/07 levels. This assumes that 2006/07 water sources continue to yield at existing rates. If existing supplies diminish, for example through the influence of climate change, then alternative water would be required.
- If all new water demand (to meet 300 L/(cap\*d) 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% (from 7 PJ in 2006/07 to 36 PJ in 2030). This would represent approximately 0.7% of projected total urban systems' energy 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% re-use and 20% new sources were estimated to require an additional 9 PJ taking total consumption to 16 PJ/a.
- The widespread adoption of low energy water-heating options (e.g. solar hot water) could reduce greenhouse gas emissions.
- 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.
- Future water strategies that consider water efficiency as well as the energy implications of water use will offer far greater scope for reductions in greenhouse gas emissions than consideration of energy use by utilities alone.

## Recommendations

The major recommendation of this report is that wider consideration, monitoring, analysis and reporting of energy use during water consumption is warranted. With improved analysis and management of energy use by utilities, energy associated with end use will help find new solutions to simultaneously reduce water and energy use. Managing energy consumed beyond traditional boundaries of responsibilities will increasingly be required to offset rapidly growing energy use within the water sector. It will also help place the energy use by utilities in context and find solutions that potentially benefit a wide range of stakeholders.

This report makes the following detailed recommendations. Some issues listed were not the specific focus of the study but are listed as a mechanism to promote discussion.

### Utility and water service provider energy use

- Improved definitions of energy needs of supply and waste water treatment and transport are required to help distinguish where in the water cycle energy is used. This is particularly important at treatment plants where intake and major distribution pumps are often located.

- Analysis of data from a larger number of utilities is needed to improve the understanding of energy used with different supply and waste water treatment processes (e.g. primary, secondary). Only data for Sydney and Brisbane were available for this part of this study.
- Improved spatial attribution of energy data to treatment and transport (e.g. mapping of energy density associated with water and wastewater treatment and transport) is warranted. This would help clarify assumptions regarding future water supply options within cities (e.g. in different areas) and the influence these strategies have on water-related energy use
- The influence of increased uptake of decentralised water supply options on energy consumption warrants further analysis.
- Analysis is needed to improve the efficiency of urban water pumping systems.
- Characterisation of a longer period of time would help detect longer-term drivers and also smooth results for local influences on particular systems that may have affected the 2006/07 result. Analysis over a longer time period would be essential to identify underlying trends and to remove variability potentially influencing some cities in the particular year analysed.
- Analysis needs to extend beyond individual water utilities. Where more than one utility is involved through the supply chain for water and wastewater services it becomes increasingly difficult to obtain 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.
- Private participation in water management is increasing and in places water cycle management is being fragmented and decentralised systems are being increasingly used. System-wide information will be necessary in future to enable decision making that provides the most cost- and energy-efficient solutions.

### **Energy use associated with water end use**

- Improved monitoring of energy associated with water end use is needed to help quantify the relationship between energy and use, and to better inform management options.
- Industrial hot water use is expected to similarly represent a significant use of energy related to water use. Improved data are necessary to characterise this.

### **Greenhouse gas emissions**

- Further analysis is necessary to characterise the links between the urban water system, water use, energy demand and greenhouse gas emissions. This will enable improved understanding of greenhouse gas emissions savings associated with any particular strategy.
- Improved tracking of greenhouse gas emissions within utilities (particularly Scope 3 and Scope 2 emissions) is necessary as relatively little data or knowledge about this issue currently exist.

### **Other recommendations**

- Public reporting of energy use associated with water use is recommended. Public reporting can help communities understand their energy use. It would also help improve associated monitoring, auditing and accounting processes. Some utilities are already reporting the estimated greenhouse gas savings attributable to water conservation measures (Sydney Water 2006). It is suggested that WSAA voluntarily adopt such reporting measures. This

would require development of appropriate reporting indicators, data definitions, monitoring programs to acquire data and 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 companies (e.g. electricity and/or gas service providers) could improve the quality of information in this effort.

- The social and economic consequences of moving to lower per-capita water consumption levels require further investigation. For example, the current low water consumption in some cities under heavy restrictions may not be socially acceptable or maintained over the long term, let alone applied to Australia as a whole.
- Life-cycle or embodied energy analysis of centralised and decentralised water service provision options including energy embodied in materials and chemicals used is needed, and should include all energy use by the industry (e.g. including accounting for energy used in transport by employees).
- Financial analysis is necessary to ensure that least-cost solutions are found, not just those that save the greatest amount of greenhouse gas emissions. Consideration of future carbon prices will also help water service providers (and others) identify the most cost-effective options.
- Analysis is recommended on other influences that can also contribute to the increasing need for energy in urban water systems (e.g. the influence of improved water treatment standards on energy use).
- Consideration of other influences outside the direct control of water utilities is suggested. For example the effect that urban form, housing stock and type, and appliances has on the overall water balance, water and energy end use associated with water utilities, and the total urban system. Clearer definition of the 'total urban system' may warrant consideration with regard to how much influence an individual is able to have on their contribution to energy use and greenhouse gas emissions.
- There is a need for a nationally coordinated approach to research and development of energy and greenhouse gas management in urban water systems.
- Further work is needed to quantify the total influence water management and policy options have on greenhouse gas emissions. This should include consideration of emissions associated with:
  - direct energy used by water utilities
  - energy used by all residential and non-residential uses of water
  - embodied energy used in the provision of water services and
  - decentralised water systems.

When all these sources of energy use are considered, it is possible that water utilities could be responsible for 3–6% of total urban systems energy use. Inclusion of fugitive emissions including NO<sub>x</sub> from wastewater treatment plants and methane from storages are also likely to contribute to the total greenhouse gas impact of urban water systems but these are not yet quantified.

## 8. DEFINITIONS

**Centralised system:** Large-scale system provided by government-regulated water utilities that supplies clean water and wastewater services.

**CO<sub>2</sub>-e (carbon dioxide equivalent):** An index that integrates various greenhouse gases associated with a system by using the global warming potential of each to weight the contributions. Approximately 300 kg CO<sub>2</sub>-e/GJ (approximately 1 kg CO<sub>2</sub>-e/kWh) is the recommended conversion factor for indirect emissions factors (full fuel cycle including Scope 2 and 3) for consumption of purchased electricity in most Australian States (Department of Climate Change 2008). Consequently use of 100 GWh (0.36 PJ) is factored to contribute approximately 100 000 t of CO<sub>2</sub>-e.

**Decentralised system:** The sourcing, treatment and provision of water services at or near the point of use. This includes on-site systems, such as rainwater tanks, owned and operated by the householder.

**Embodied energy:** the energy required by all activities associated with a production process, including the relative proportions consumed in all activities upstream of 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]).

**Energy intensity:** A measure of the energy required to pump or treat clean or waste water.

**Full fuel cycle (FFC) emission factor:** The quantity of emissions released per unit of energy for the entire fuel production and consumption chain. For fuel combustion, the FFC emission factor is the sum of the fuel's direct emission factor, and the specific 'Scope 3' emission factor for the emissions from extraction, production and transport of the fuel. For the consumption of purchased electricity, the FFC 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' factor for emissions from extraction, production and transport of that fuel and for emissions associated with the electricity lost in transport (Dept of Climate Change 2008).

**Operational energy:** Energy used for the operation of the water supply and wastewater system (as distinct from embodied or life cycle energy requirements).

**Primary wastewater treatment:** The first major treatment process in wastewater treatment, principally designed to remove substantial amounts of suspended matter. Processes may include clarification (to separate liquid and solids), grease removal and screens (WSAA and NWC 2007).

**Secondary wastewater treatment:** A biological treatment process designed to remove 85% of biological oxygen demand and influent suspended solids. Some nutrients may be removed and ammonia may be converted to nitrate. Secondary treatment processes include sand filtration, disinfection, polishing (to lower suspended solids and bacterial levels), activated sludge, 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 as phosphorus and nitrogen. A high percentage of effluent suspended solids removal (typically >95%). Typical biological nutrient removal plants, chemical dosing of secondary plants (including lagoons), enhanced pond treatment systems, reverse osmosis and advanced filtration systems, membrane bioreactors and secondary treatment plus grass plots or wetlands (WSAA and NWC 2007).

**Treatment energy:** Energy necessary to treat water or wastewater including energy to pump/pressurise water (e.g. for reverse osmosis), and to move on-site water 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, disposal or 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 system's energy use was estimated as the pro-rata proportion of total energy use for the state in which the city is located.

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## APPENDIX 1: RAW DATA FROM WATER UTILITIES 2006/07

Table 16 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 (NZ)	Metrowater (NZ)
Population	4 300 000	N/A	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	N/A	–	107	170	61	40	111	N/A	–
Wastewater collected (GL)	508	N/A	296	108	119	86	47	88	104	53
Total energy (GJ)										
Water supply – pumping	476 298	1 211 662	86 185	16 321	423 000	28 245	39 416	1 041 901	39 327	1 711
Water supply – treatment	186 009	N/A	12 860	Not reported	409 000	246 337	9 234	55 418	56 749	–
Wastewater – pumping	119 916	N/A	436 467	9 686	92 800	39 726	50 030	32 064	37 978	1 573
Wastewater – treatment	698 205	N/A	645 715	38 970	213 000	138 028	119 389	185 194	273 293	100
Other energy demand	220 522	30 316	67 000	26 970	162 700	49 070	39 461	123 240	23 157	–
All demands	1 700 950	1 241 979	1 248 227	91 947	1 300 500	501 406	257 530	1 437 817	430 504	–
Greenhouse gas emissions – total reported (or FFC) for energy-related sources (t CO <sub>2</sub> -e)										
	448 282	326 110	233 633	28 482	312 850	138 000	74 505	392 486	31 883	–

*N/A not applicable; – no data provided*

*Source: Water utilities contributing to this survey.*

## APPENDIX 2: GREENHOUSE 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](http://www.ghgprotocol.org)>. The GHG Protocol defines three 'scopes' of emission categories (see Figure 18):

- **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, which would lead to double counting.
- **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.

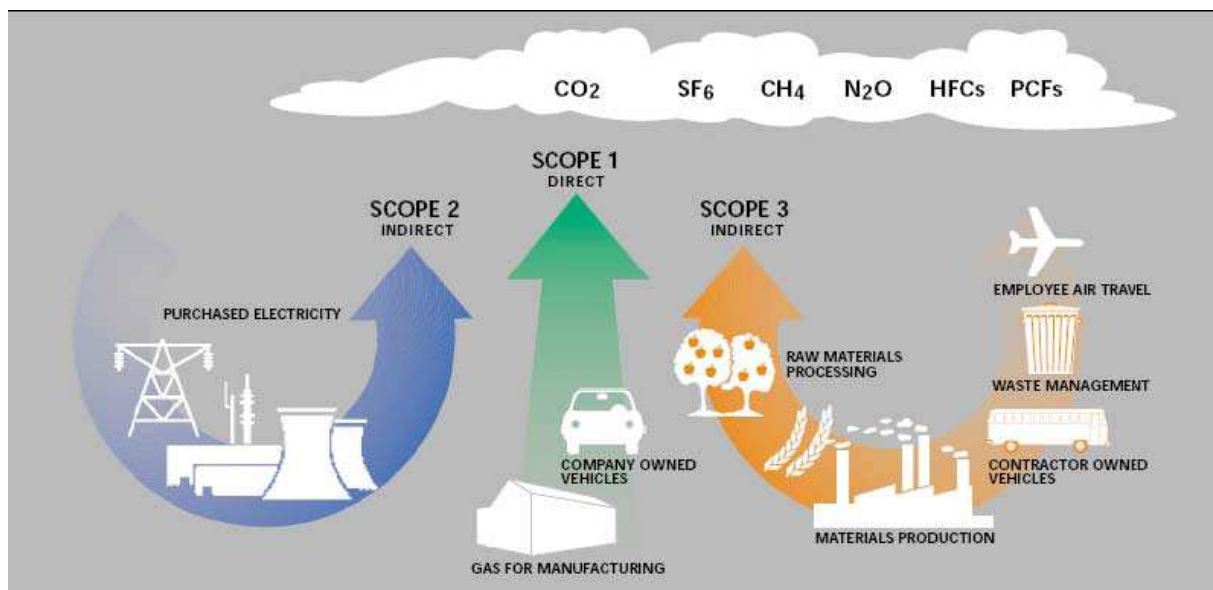


Figure 18 Scope of greenhouse gas emissions

Source: New Zealand Business Council for Sustainable Development

## APPENDIX 3: RESIDENTIAL AND URBAN SYSTEMS ENERGY USE

Table 17 shows the change in energy demand by city over the period 1996 to 2005 (see also Figure 19). This shows the greatest growth in energy demand 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 17 Residential energy use by city (PJ)**

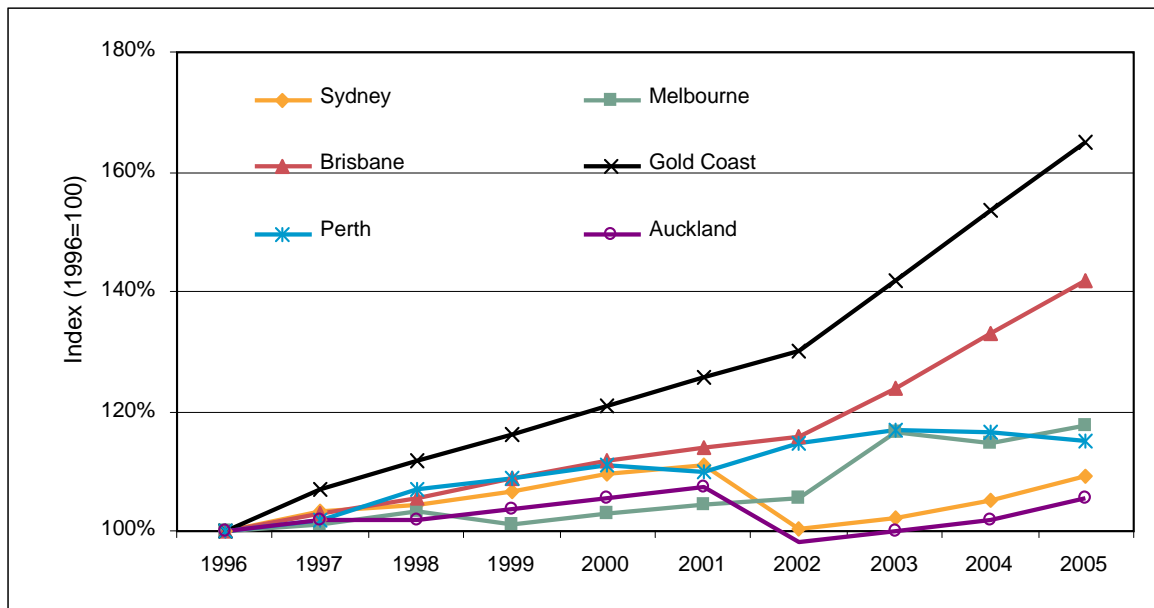
	Sydney	Melbourne	Brisbane	Gold Coast	Perth	Adelaide	Total (Aust cities)	Auckland*
1996	67.7	102.1	17.9	4.3	22.0	21.4	235.8	16.4
1997	69.9	103.3	18.4	4.6	22.4	22.0	241.2	17.1
1998	70.7	105.3	18.9	4.8	23.5	22.4	246.2	17.5
1999	72.2	103.4	19.5	5.0	23.9	22.6	247.4	17.8
2000	74.1	105.1	20.0	5.2	24.4	22.9	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 18 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
<b>Total</b>	<b>15 833 000</b>	<b>5 002</b>

Sources: Projected population – WSAA 2005. Estimated energy – Cuevas-Cubria and Riwoe 2006. The energy projection for cities was taken as pro rata based on proportion of total state population residing in a city. Note that the population for Brisbane is not just Greater Brisbane which was estimated by Birrell (2005) to have a population of 2.547 million by 2031).



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

The greatest increase in greenhouse gas emissions for urban areas from 1996 (Figure 20 and Figure 21) has been recorded by the Gold Coast. This is a relatively small proportion of total emissions. 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.

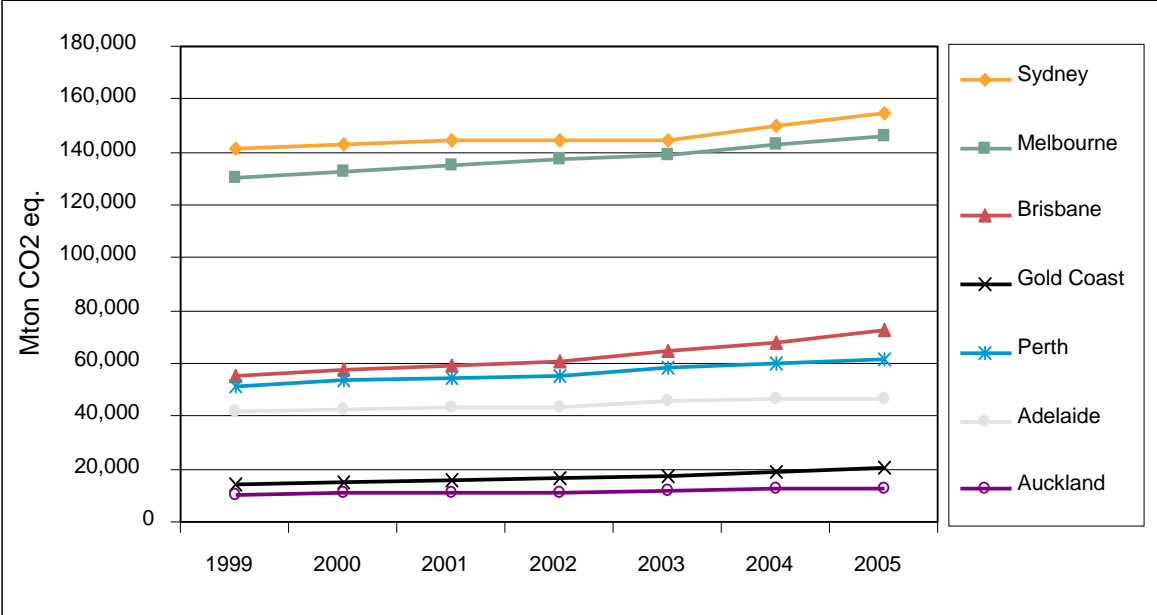


Figure 20 GHG emissions for cities (Mt CO<sub>2</sub>-e; 1996–2005)

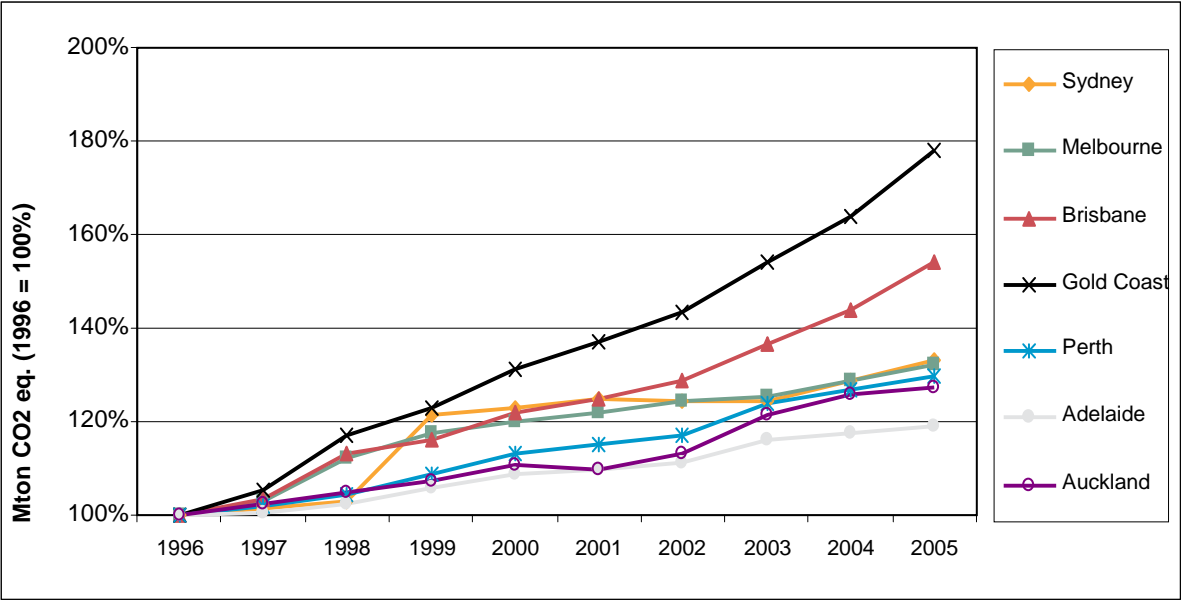


Figure 21 Change in the GHG emissions for cities (1996–2005)

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. Emissions from electricity generation comprise 70% of Australia’s stationary energy greenhouse gas emissions, with most demand for electricity being driven by industrial and residential sectors of the major urban centres (Pears 1996).

**Table 19 Concentration of population (%) in urban centres (2006)**

	Sydney	Melbourne	Brisbane	Gold Coast	Perth	Adelaide	Auckland
Percent by state	63	73	45	13	74	74	–
Percent 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 – there is often 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.



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