Trajectories of Change: Melbourne's population, urban development, energy supply and use from 1960-2006

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Abstract

This paper presents data from the recent history of operational energy demand and supply for Melbourne, the major urbanised area of the State of Victoria, Australia. We discuss the historical path that has led to the current state of energy consumption and elements of future scenarios. This is a working paper for the Global Energy Assessment (GEA) project being coordinated by the International Institute for Applied Systems Analysis (IIASA). One aim of the GEA project is to provide technical and scientific support for decision-making by evaluating the range of social, economic, development, technological, environmental, security and other issues linked to energy. Part of this endeavour is to present urban energy case studies of which this is one.

Introduction

Since 1961 Melbourne's demand for energy has nearly tripled (276% increase) even while the business of the city has moved away from industry towards the service sector. We suggest that this is driven directly, by increases in the size of the total population (75%) and changes to the energy lifestyle of Melbourne's inhabitants, represented in per-capita energy requirements (120%) and also indirectly through the increase in space occupied by residential areas (160%). Following World War II the population and economy of Melbourne expanded rapidly and this coincided with an increase in automobile ownership. Early planning strategies allowed for geographical expansion, further entrenching automobiles as the dominant mode of personal transport. The legacy of that era is a dispersed city which today has an area approximately twice the size of Paris with only 2/3 of the population. Historically, Melbourne has been dependent on local brown coal for electricity production and the State of Victoria has increased its coal-powered generation capacity over the last 40 years both in absolute and relative terms (the fraction of electricity generated using coal has increased from 75% to 96%). While this has locked-in coal dependence for some decades to come, an increasing component of total energy needs is being provided by natural gas and renewable sources. In addition to global drivers such as climate change and peak oil, there are several, more local, factors that may affect demand: plans for higher density living near activity hubs separate from the CBD, eco-sensitive new buildings and retro fittings and a nationally implemented emissions trading scheme.

To appreciate the current state and near future of any city, it is instructive to consider the legacy of its past. There have been a number of changes to the form and function of Melbourne since it was established in 1835 and what follows is a short description of the growth and development of Melbourne including transitions in the main business of the city, how that has affected its energy needs and how those needs have

been met. We define the metropolitan area of Melbourne to be the same as that of Melbourne Statistical Division shown by the outer boundary in Figure 1.

Melbourne

As with most cities, Melbourne was sited around fertile lands that provided food, energy and the basis of a formative economy. Unlike many cities, Melbourne was well planned with Robert Hoddle laying down the central street plan in 1837 and from that point onwards, Melbourne has always been generously spaced in terms of land available for housing and the area of land allowed for wide roads, avenues, parks and public spaces. Initially, with a small population, this permitted people from a wide range of socio-economic backgrounds to afford high quality low density housing close to the city. This egalitarian tradition has produced a broad skirt of low density housing punctuated with several local centres but anchored by transport routes to a central core (refer to Figure 1).

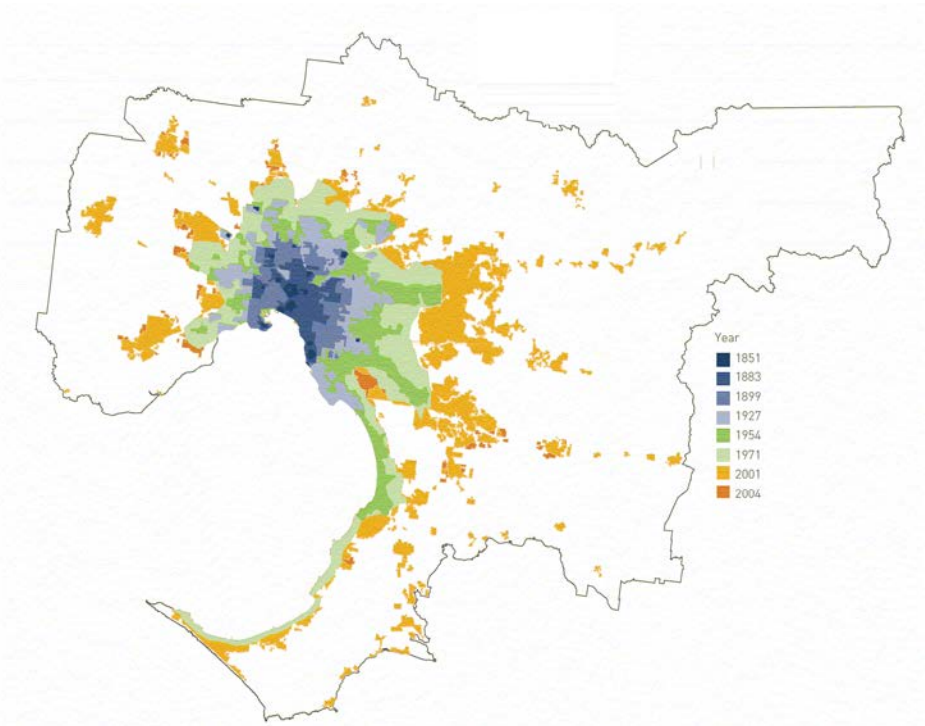


Figure 1 Historical land development around Melbourne as defined by the boundary of Melbourne Statistical Division (from Atlas of Melbourne 2006 p1.2)

During the gold rush years (~1850-1870) immigrants flocked to Victoria's gold fields. The wealth generated in this era established Melbourne as a seat of commerce, finance and governance and to this day, the headquarters of several mining companies reside in Melbourne though mining activity now occurs predominantly in Western Australia.

A hundred years later, following World War II (WWII), immigrants again boosted Melbourne's population from 1.34 million in 1947 to 2.5 million in 1971 (ABS 2006). During this time there was an extended period of economic expansion known as the 'Long Boom' wherein Australia generally experienced great success with agricultural exports and cities were co-beneficiaries (Forster 1996). Melbourne was no exception and with an increase in material wealth and, in particular, the ownership of

automobiles, there was a concomitant geographical expansion and increase in the consumption of energy (see Figure 2). Between 1971 and 2005 Melbourne's population grew by a further 44% though conservative governance in the early to mid 1990's saw a strong emphasis on business developments in the centre of the city and further growth in the residential outer fringe, particularly to the west and south east (ABS 2006). During this time the areas closest to the CBD experienced depopulation though there has been a recent trend towards rejuvenation (Social Atlas of Melbourne 2006)

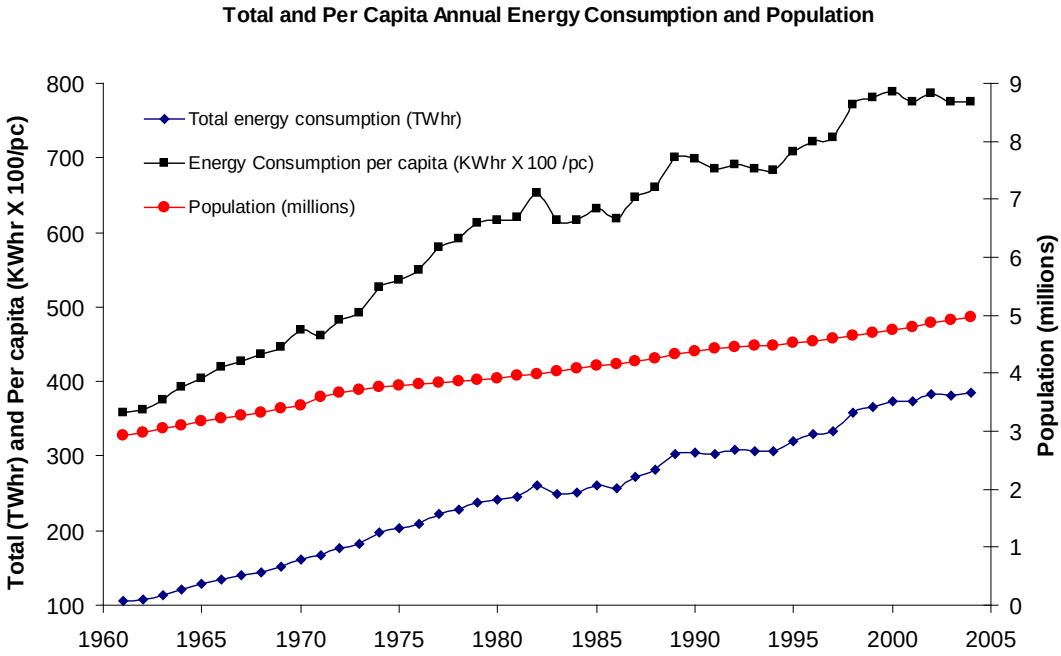


Figure 2. Total and per capita primary energy consumption (left hand axis) and population (right hand axis) for the State of Victoria between 1960 and 2005

During and after WW II, Melbourne developed a significant manufacturing sector notably in its contribution to Australia's automobile industry (see p13 of Forster (1996)). The census of 1947 reported that for the first time more Australians worked in manufacturing (28%) than in primary industries (18%). By 1971 more than a third of jobs in Melbourne were in manufacturing.

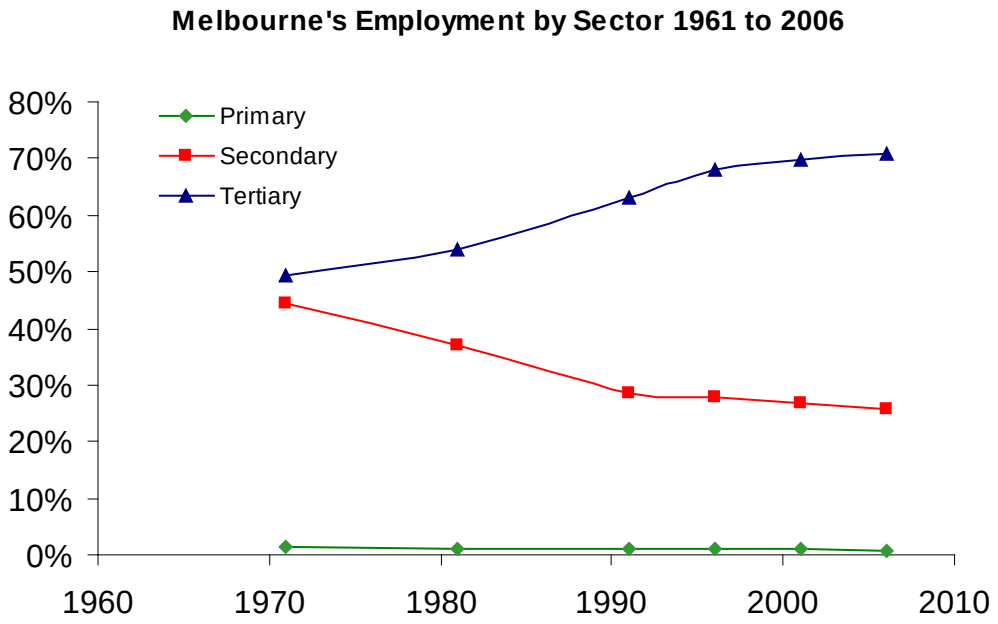


Figure 3.Proportion of Melbourne's workforce in primary, secondary and tertiary industries. Secondary includes those employed in utilities and transport (from ABS (2006)).

However, as Figure 3 demonstrates, over the last 30 years there has been a marked reduction in employment in secondary industries at the same time as a substantial increase in the proportion of people employed in service industries. This may be indicative of a change in the function of the city with the fraction of people employed in manufacturing halving from 31% to 16% while the contribution of financial, property and business services increased from 8% to 18%. At the same time the proportion of people employed in hospitality and entertainment increased from 5% to 10%.

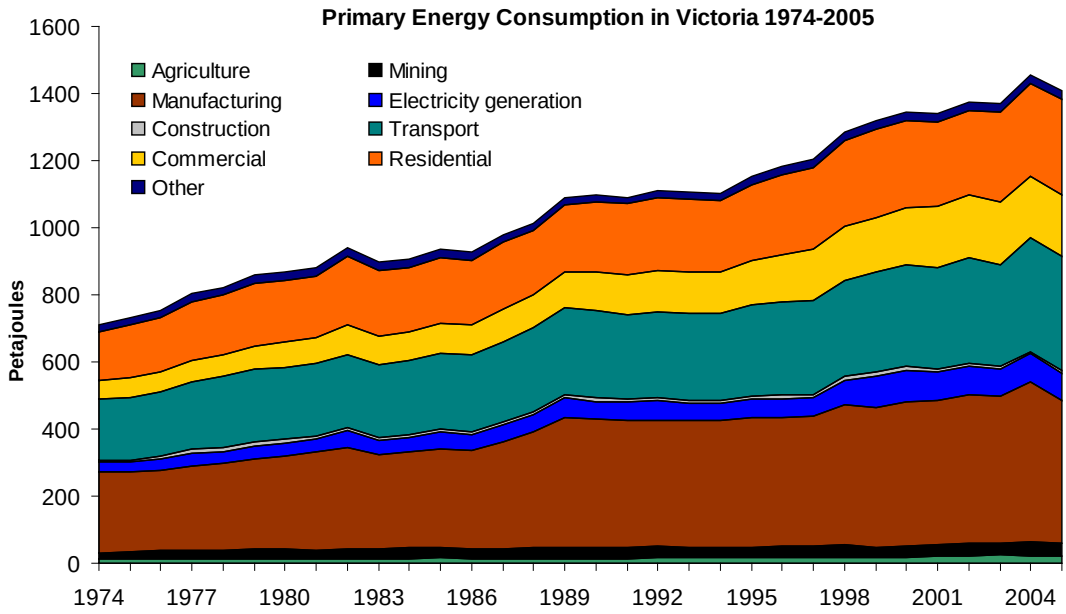
It is tempting to assume that a transition to a more serviced based economy might also engender lower energy costs but as recent research (Foran et al. 2005; Oliver-Solà et al. 2007) has pointed out, service industries still have significant material and energy needs.

Energy Demand

Industrial

Despite the evident changes in the functional character of Melbourne, the proportions of sectoral energy demands across the State of Victoria have remained reasonably stable for the last 30 years (refer to Figure 4). The four sectors that have always consumed the most energy are, in order: the transport, manufacturing, residential and commercial sectors. One possible explanation of this broader stability is that as Melbourne's footprint expanded and the city transitioned to a service-based economy, the primary and secondary industries simply relocated or were established elsewhere in the state.

a)



b)

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Figure 4. a) Historical primary energy consumption in Victoria by sector and b) estimated primary energy consumption for Melbourne (data derived from ABARE (2006))

While a new paper processing plant was established in Melbourne in the 1980's, a more energy intensive aluminium smelter was commissioned in Portland in the state's west.

Figure 5 shows how the 84% increase in total primary energy demand is broken down by sectors. While this data is for all of Victoria, energy demand has increased most in the residential, commercial and transport sectors and from this we can infer that the *change* in energy consumption has been most pronounced in urban areas.

Contribution to change in Final Energy Consumption for Victoria between 1974 and 2005

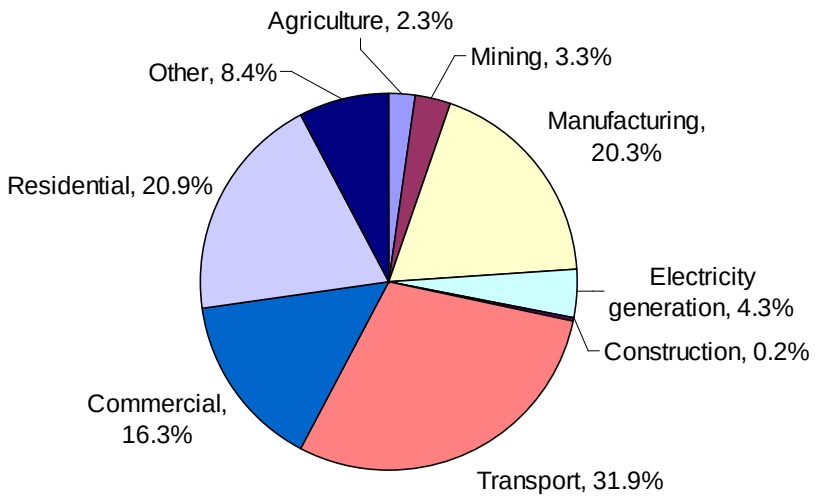

Figure 5. Sectoral contributions to the change in energy demand between 1974 and 2005 for all of Victoria. The residential, commercial and transport sectors dominate and these are strongly associated with urban growth.

For all the transformations of the work force, the manufacturing sector still has the largest primary energy requirement, in absolute terms, and Melbourne retains the legacy of a more industrial age. Since 1924 there has been an oil refinery about 10km south west of the city at Altona and a related petrochemical plant was established there in 1961. Nearby there is also an electric arc steel furnace at Laverton (operating since 1983) and there are other industrial areas in the north west and south east.

Data for energy use by industry has only been collected consistently since 1973 and only at the State level. However, we have used a combination of land use information and knowledge of the sites of energy intensive industries to generate data for Melbourne. Refer to the Appendix section at the end of this paper for more details.

Table 1. Energy account for Melbourne 2005

	Brown Coal	Brown Coal Briquettes	Oil	Oil products	Gas	Hydro	Electricity	Total
Primary Energy Production			244.65					244.65
Import	0.01	3.59		0.55	168.66		120.24	293.05
Export								0.00
Stock Changes								0.00
Total primary energy consumption	0.01	3.59	244.65	0.55	168.66		120.24	537.70
Electricity Generation				-0.24	-14.73		0.29	-14.68
Conversion to other fuels			-244.65	232.62				-12.03
Own needs				-12.03			-17.44	-29.47
Losses					-1.41			-1.41
Final energy consumption	0.01	3.59	0.00	220.91	152.51		103.09	480.11
Agriculture and Forestry				0.46	0.00		0.04	0.50
Mining				0.36	6.50		1.35	8.21
Industry total	0.01	1.11		6.39	48.16		28.98	84.66
Petroleum and Chemical		0.79		2.13	17.58		5.34	25.84
Machinery and Metal Processing				3.64	6.04		14.89	24.56
Textile and Clothing		0.27		0.03	2.33		0.37	3.00
Wood, paper and printing				0.07	7.29		4.08	11.44
Food and Beverages		0.06		0.08	9.53		3.04	12.72
Other manufacturing	0.01			0.44	5.39		1.26	7.11
Construction				5.04	1.98		0.11	7.13
Commercial and Services		2.39		1.39	23.67		36.16	63.61
Transport (excluding Int. travel and				205.15	0.03		1.42	206.59
Road				173.44	0.03			173.46
Railway				1.10			1.42	2.52
Water				13.89				13.89
Domestic Air				16.72				16.72
Residential		0.09		1.79	66.66		33.81	102.35
Water and Gas Utilities				0.33	5.51		1.21	7.05

Table 2. Energy account for Victoria in 2005

	Brown Coal	Brown Coal Briquettes	Oil	Oil products	Gas	Hydro	Electricity	**Total**
Primary Energy Production	693.2		461.6		264.0	2.8		1421.6
Import							8.1	8.1
Export				-63.1			-17.7	-80.8
Stock Changes		4.8						4.8
Total primary energy consumption	693.2	4.8	461.6	-63.1	264.0	2.8	-9.6	1353.6
Electricity Generation	-684.4	-2.9		-0.5	-26.3	-2.8	224.9	-491.9
Conversion to other fuels	-4.0	3.0	-461.6	438.9				-23.7
Own needs				-22.7			-31.2	-53.9
Losses					-2.22			-2.2
Final energy consumption	**4.8**	**4.9**	**0.0**	**352.6**	**239.9**	**0.0**	**184.2**	**786.4**
Agriculture and Forestry	0.0	0.0		17.2	0.0		1.5	18.6
Mining	4.8	0.0		1.0	18.2		3.8	27.7
Industry total	*0.0*	*2.1*	*0.0*	*13.0*	*93.4*		*88.4*	*197.0*
Petroleum and Chemical	0.0	1.5		4.0	33.2		10.1	48.8
Machinery and Metal Processing	0.0	0.0		7.7	12.8		61.6	82.1
Textile and Clothing	0.0	0.5		0.1	4.4		0.7	5.6
Wood, paper and printing	0.0	0.0		0.1	13.7		7.7	21.5
Food and Beverages	0.0	0.1		0.2	17.9		5.7	23.9
Other manufacturing	0.0	0.0		0.9	11.4		2.7	15.1
Construction	0.0	0.0		5.0	2.0		0.1	7.1
Commercial and Services	0.0	2.7		1.6	26.6		40.6	71.4
Transport (excluding Int. travel and bunkers)	*0.0*	*0.0*		*311.9*	*0.0*		*1.4*	*313.4*
Road	0.0	0.0		273.0	0.0		0.0	273.1
Railway	0.0	0.0		3.7	0.0		1.4	5.1
Water	0.0	0.0		18.5	0.0		0.0	18.5
Domestic Air	0.0	0.0		16.7	0.0		0.0	16.7
Residential	0.0	0.1		2.5	92.1		46.7	141.4
Water and Gas Utilities	0.0	0.0		0.5	7.6		1.7	9.7

Residential requirements

The 21% increase in energy consumption since 1974 and the two-fold increase in per-capita primary energy demand since 1960 indicate that there have been changing consumption patterns in the residential sector. There is evidence to suggest that this has been manifested in increases in material wealth and mobility. The first of these is demonstrated in Figure 6 which shows the penetration of electricity appliances in Victoria since 1983.

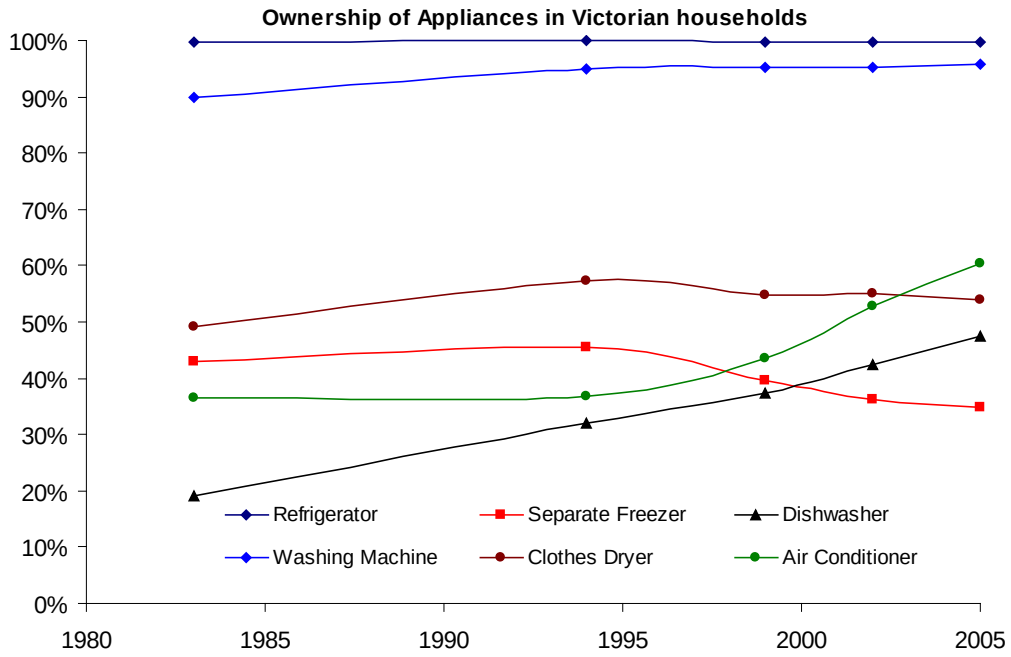

Figure 6. Market penetration of appliances in Victorian households. Data from ABS (1995; 2005).

Note in particular the increased (> 20%) uptake of air conditioners and dishwashers. The data in Table 3 for Melbourne and Victoria demonstrates that the characteristics of urban households are comparable with those for the whole state (for 2005). The only significant (> 5%) difference is in the ownership of separate freezers which occurs relatively less in the city.

Table 3. Penetration of appliances in Melbourne compared with all of Victoria for 2005. Data from ABS (2005).

	Refrigerator	Separate Freezer	Dishwasher	Heater	Washing Machine	Clothes Dryer	Air Conditioner
Melbourne	99.8%	27.2%	51.6%	98.1%	94.9%	52.7%	58.7%
Victoria	99.8%	34.9%	47.5%	98.1%	95.8%	54.0%	60.5%

According to a report for Victorian Energy Networks Corporation (EES 2005): “From the mid 1990’s, rapid increases in the penetration of air-conditioners, particularly in the residential sector, has resulted in Victorian peak electricity demands consistently occurring during summer. Prior to this, peak demands consistently occurred in the winter season” – see Figure 7.

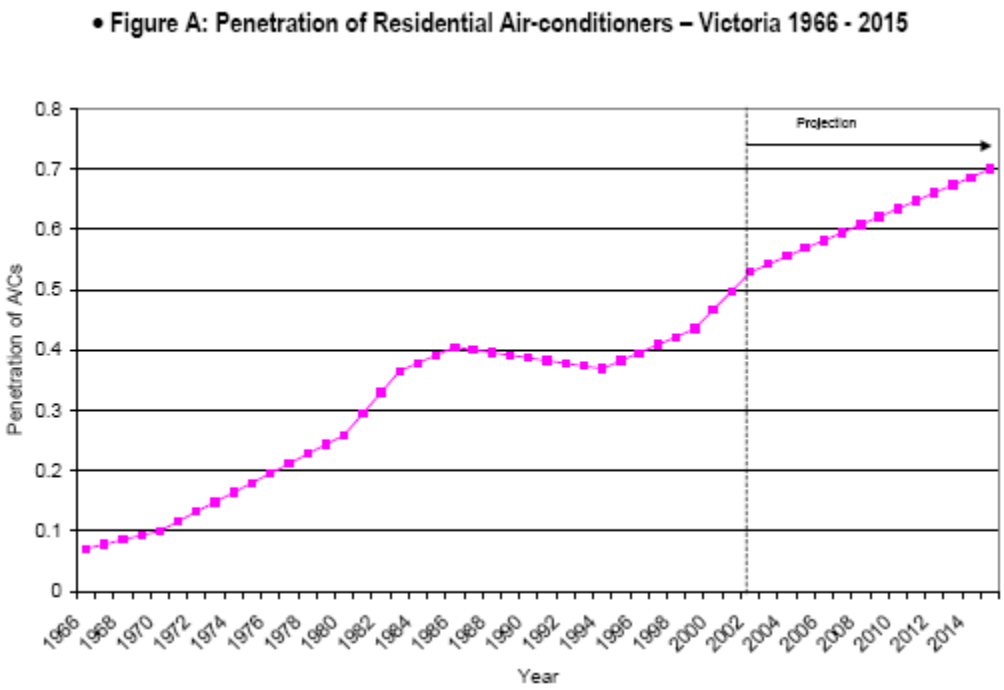

Figure 7. Data courtesy of VenCorp and Energy Efficient Strategies (EES 2005)

In addition to the increased ownership of appliances, the size and location of houses in Melbourne has changed. Since 1984 new houses in Victoria have increased their floor space by 36% (ABS 2005). In 1954, 70% of Melbournians lived within 10km of the city CBD and the average population density was 8.4 persons per hectare (pph). By 2001 84% lived further than 10km from the city which was partly explained by the population doubling but the average density had also dropped to 4.8[α] pph (DPCD 2007).

Several studies have found correlations between energy consumption and the size and location of housing (Perkins 2003) and the type of housing (Newton et al. 2000) in Australian cities. Newton et al. calculated embodied, operational and life cycle energy costs for detached houses and apartments in major Australian cities (see Table 4). While detached houses have more than double the initial embodied energy of apartments, they are also more likely to have more occupants and the result is that the two types of dwelling are roughly equivalent in life cycle energy measured in Gj/occupant.

However, a decreasing occupancy of medium density and detached houses has been the trend for Melbourne over the last 30 years (ABS 2006). The cumulative effect of the above statistics can be summarised coarsely as follows: at the same time that the total population has been increasing, an increasing number of larger houses have been built that are occupied by fewer people who generally own more appliances than their predecessors. This statement is, of course, a very broad generalization and there are suburbs where much of that description does not apply, but it does convey the essence of the lifestyle change that has occurred over the *whole* city since the 1960's.

[α] The boundary definition of Melbourne has been enlarged since 1954 but the calculation of this density excludes the rural areas of Hume and the Yarra Valley currently contained within Melbourne statistical division.

Table 4. Energy intensities of different types of dwelling in Melbourne. Data extracted from Newton et al. (2000).

Location and level of insulation	Detached House				Apartment			
	Initial embodied energy (GJ)	Annual heating/ cooling energy (MJ/m²)	Life cycle energy (GJ/m²)	Life cycle energy (GJ/per occupant)	Initial embodied energy (GJ)	Annual heating/ cooling energy (MJ/m²)	Life cycle energy (GJ/m²)	Life cycle energy (GJ/per occupant)
Brisbane								
High	1027	42	12.8	898	445	48	12.9	652
Medium	1017	51	13.4	940	445	69	14.6	738
Low	993	115	18.3	1294	481	98	17.3	875
Sydney								
High	1027	47	13.2	926	445	47	12.8	647
Medium	1017	70	14.9	1045	445	78	15.3	774
Low	993	156	21.6	1515	481	111	18.4	931
Melbourne								
High	1027	143	20.9	1466	445	210	25.8	1305
Medium	1017	198	25.2	1768	445	283	31.7	1603
Low	993	273	30.9	2167	481	356	38.0	1922

Perkins (2003) surveyed 200 households from another Australian city (Adelaide) and found that dwelling size, car ownership and location correlated strongly with the life cycle energy consumption of households (Figure?).

Ownership of cars in Melbourne has multiplied more than 6 times in 50 years from 112.5 cars/1000 people in 1950 to 679.8 /1000 people in 2004 (DPCD 2007). Melbourne shares with Perth the highest level of automobile ownership in Australian cities with 35% of Melbourne households having at least 2 cars (Commissioner for Environmental Sustainability 2006).

The raw data on energy use does not specify how or why residential demand has increased but much can be attributed to the substantial changes to the area and density of the urban form; to the size and type of dwellings; to the number of appliances used therein; and to the ownership and use of private automobiles.

Transport

This sector has contributed most to the increase in final consumption for Victoria over the last 30 years and although there have been improvements in the efficiency of motor vehicles in that time, there has also been a concurrent increase in their use and changes to the popularity of different transport modes.

Melbourne retained its trams when other Australian cities were retiring them in the 1950s and 60s, but there has been a strong trend across all urban centres in Australia towards automobiles in the last 60 years. In 1945, approximately 50% of the urban transport task was conducted using the automobile, by 1997 this was more than 90% (BTE 1998). Between 1971 and 1995 the total distance travelled per year by all vehicles in Australia doubled (to 166 billion vehicle-km) and passenger vehicles accounted for three quarters of the total. Within Melbourne the number of passenger-km has also doubled between 1977 and 2005 (see Figure 8). Though some of this is explained by the increase in population (33%) clearly, most of that change can be attributed to increased car use per person.

The kilometres travelled by bus in Melbourne has remained fairly constant since the 1970's but the number of people using public transport declined from a peak of over 500 million trips per annum in 1950 to less than 300 million trips in the 1980s rising more modestly to about 350 million trips at the present time (BTE 1998). The annual kilometres travelled by the average Melbournian is now 14 000km (the second highest in Australian cities) and this is likely to increase (BTRE 2007).

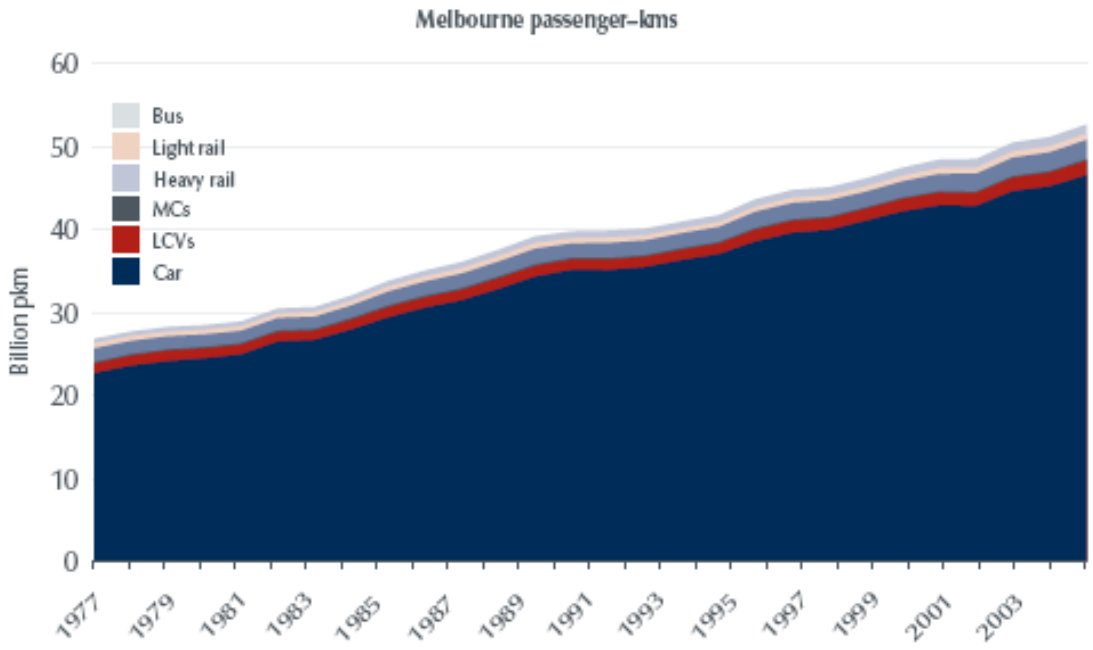

Figure 8. Historical trend in Melbourne passenger-kilometres by mode, 1977-2005 used with permission from the Bureau of Transport and Regional Economics (2007). MC - motorcycles; LCV – light commercial vehicles

The energy intensity of urban passenger transport in Melbourne is shown in Table 5 after Lenzen (1999) who included the fuel, operation and maintenance of each transport mode in his calculation. The product of these intensities with the data on passenger-km above, suggests that the current energy required by Melbourne passenger automobiles alone is approximately 200PJ, nearly half of Victoria's petroleum energy budget.

Table 5. Energy intensities of difference modes of passenger transport in Mj/passenger-km

Mode	Megajoules/passenger-km
Light rail	2.0
Heavy rail	3.3
Bus	3.8
Bicycle[β]	0.7
Automobile – petrol (LPG, diesel)	4.4 (4.8, 4.8)

β includes energy required for food production, maintenance and street lighting

Lenzen (1999) also states that over the complete life cycle of use, public transport modes (bus, tram, train) use on average, 2/3 of the energy and produce 2/3 of the greenhouse gas per passenger km of passenger vehicles.

This average is deceiving because at peak times buses and trains are considerably more loaded than cars. Energy intensity of cars at peak hour is about 6.5 Mj/passenger.km whereas public transport has a per passenger km energy intensity of 1-2 Mj. At off peak times the car occupancy rates are higher and the public transport modes are lower.

Energy Supply

Melbourne's primary energy supply is currently dominated by three fuel sources: brown coal, petroleum products (including diesel) and natural gas (refer to Figure 9). With state-wide distribution networks and the possibility of inter state energy trading from the late 1980's, it is difficult to determine what source of energy has been consumed where. The derived data of Figure 9 assumes that the history of energy for Melbourne strongly parallels the history for Victoria though there are some regional specifics such as the gas-powered electricity generator at Newport used predominantly for Melbourne's peak loads.

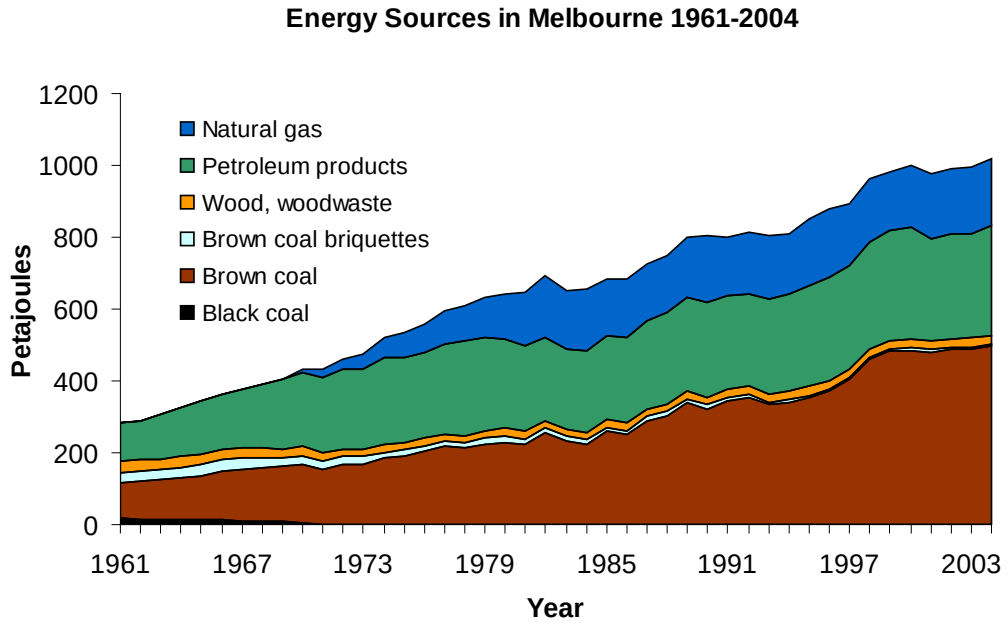

Figure 9. Sources of energy for Melbourne between 1961 and 2004 by fuel type. Derived data using the totals for fuel consumption for Victoria multiplied by the proportion of population living in Melbourne. This is based on the state-wide grid distribution of electrical power and the use of automobiles by people. The contribution from renewable energy sources was too small to show. Data from the Australian Bureau of Agriculture and Resource Economics (2008).

Brown coal is the primary fuel source for electricity generation and it is found locally in the Latrobe Valley, 130km to the east of the city but outside our definition of the Melbourne metropolitan area. In the 1960's, 75% of Victoria's electricity was generated using brown coal either in its raw form or manufactured into brown coal briquettes (ABS 1966). Today this is 96% with the remainder of electricity generation powered by natural gas (1.6%) and renewable energy sources (2.4%) (DPCD 2007).

Table 6. Victoria's electricity generation capacity by location, type and size of plant and year commissioned. An (e) indicates that the electricity generation is embedded within a community, business or industry (data from the Energy Supply Association of Australia Ltd. (ESAA 2005))

Power Station	MW	Type	Location	Year of commission
Challicum Hills (e)	52.5	Wind	Challicum Hills	2003
Toora (e)	21	Wind	Toora	2003
Valley Power	300	Gas turbine/gas	Latrobe Valley	2002
Somerton	160	Gas turbine/gas	Somerton (Melbourne)	2002
Bairnsdale	92	Gas turbine/gas	Bairnsdale	2001
Codrington (e)	18.2	Wind	North-east of Portland	2001
Lake Glenmaggie (e)	3.8	Hydro	Lake Glenmaggie	1994
Lake William Hovell (e)	1.55	Hydro	Lake William	1994
Silvan Cardinia (e)	5	Hydro	Silvan Cardinia	1994
Loy Yang B	1000	Steam/coal	Latrobe Valley	1993
Cardinia Creek (e)	3.6	Hydro	Cardinia Creek	1993
Blue Rock (e)	2.2	Hydro	Blue Rock	1991
Maryvale (e)	18.5	Black liquor	Maryvale	1989
Loy Yang A	2085	Steam/coal	Latrobe Valley	1984
Thomson (e)	7.5	Hydro	Thomson	1983
Yallourn W	765	Steam/coal	Latrobe Valley	1981
Dartmouth	150	Hydro	Dartmouth	1980
Jeeralang B	449	Gas turbine/gas	Latrobe Valley	1980
Newport	510	Steam/gas	Newport (Melbourne)	1980
Jeeralang A	449	Gas turbine/gas	Latrobe Valley	1979
Maryvale (e)	36	Black liquor	Maryvale	1976
Yallourn W	700	Steam/coal	Latrobe Valley	1973
Anglesea	160	Steam/coal	Anglesea	1969
Corio (Shell refining) (e)	44.4	Cogen/waste gas	Corio	1968
Hazelwood	1600	Steam/coal	Latrobe Valley	1964
Morwell	30	Steam/coal	Latrobe Valley	1962
McKay Creek	150	Hydro	Kiewa	1960
Cairn Curran (e)	2	Hydro	Cairn Curran	1960
Morwell	90	Steam/coal (cogen)	Latrobe Valley	1958
Morwell	75	Steam/coal (cogen)	Latrobe Valley	1958
Hume Vic	29	Hydro	Hume Weir, Albury	1957
Eildon	120	Hydro	Eildon	1956
West Kiewa	62	Hydro	Kiewa	1955
Clover (e)	29	Hydro	Kiewa	1944
Lower Rubicon (e)	2.7	Hydro	Rubicon	1928
Royston (e)	0.85	Hydro	Rubicon	1928
Rubicon (e)	13.55	Hydro	Rubicon	1928
Rubicon Falls (e)	0.3	Hydro	Rubicon	1926
Eildon (e)	4.5	Hydro	Eildon	N/A
Petroleum/Esso-LIP (e)	32	Steam/waste gas	Long Island Point	N/A

About 10km south west of Melbourne's CBD is a complex of power stations at Newport. Newport A, B, and C coal-fired plants operated at the site between 1918 and the 1970s initially using imported black coal and brown coal briquettes from Yallourn to supply electricity for the tram system. Coal is no longer used and the Newport D 500 MW gas-fired plant has operated since 1981 providing peak load electricity.

In 1965 natural gas reserves were discovered off the southern coast of Victoria in Bass Strait and a pipeline into Melbourne (at Dandenong) was constructed in 1969. Natural gas has steadily increased its prominence as a fuel source for electricity generation, transport, heating and residential uses (see Figure 9 and Figure 10). Between 2001 and 2002 gas-powered electricity generation capacity in Victoria more than doubled with the addition of another 552 MW of capacity. 160MW of this is located within the Melbourne suburb of Somerton.

The Snowy Mountains Hydro-electric Scheme was constructed between 1949 and 1974 progressively increasing installation of hydro-electric generation capacity up to 4 GW. The electricity from this scheme is shared between the Commonwealth of Australia, New South Wales and Victoria but Victoria has access to more than 500 MW of its own hydro power and there has been some recent investment in embedded renewable energy generation. The 654MW of new generation capacity installed in the last 15 years has been powered either by natural gas or from renewable energy sources (see also Figure 10 and Table 6). This, however, is to be compared to prior investment in coal-fired power stations: 1000MW in 1993 and 2085MW in 1984, both still operating.

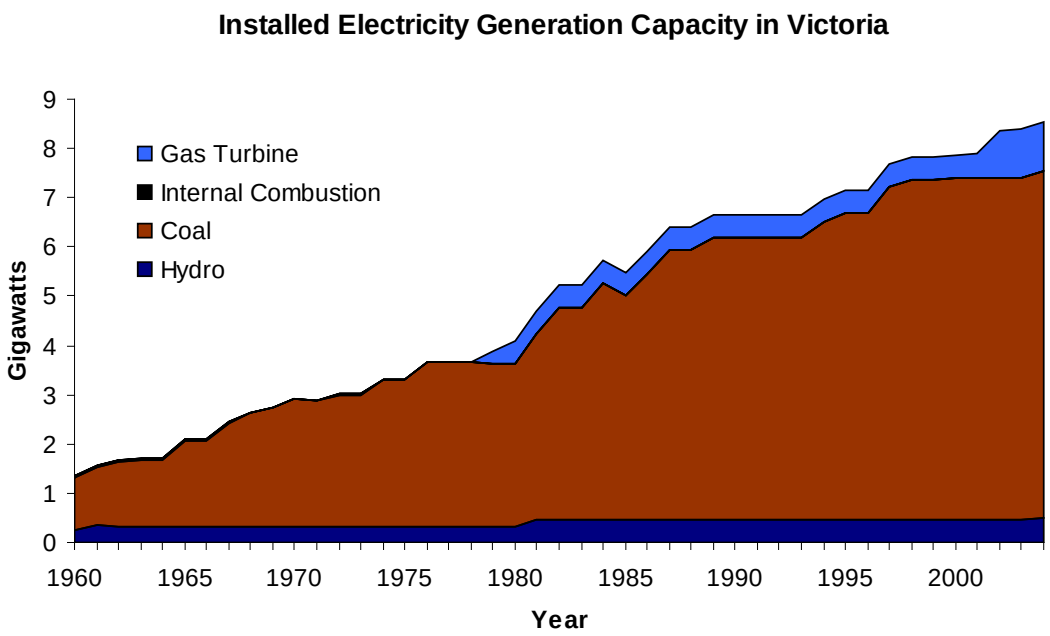

Figure 10. Electricity generation capacity installed for the State of Victoria. Note that some very small renewable plant is not shown (there is < 100MW of wind generated electricity capacity). Data from the Energy Supply Association of Australia Ltd. (ESAA 2005).

The oil refinery at the Melbourne suburb of Altona has a capacity of 6.16 Mt/year which is approximately 55% of the State's capacity. According to Collins and Powell (2002) these plants operate at an annual average of 85-88% of their rated capacity

indicating a current output of about 300PJ of oil products per year[γ]. The other major Victorian oil refinery at Geelong (70km from Melbourne) has a capacity of 5.34 Mt/year (approximate output ~ 265 PJ) and in combination these plant can comfortably provide for the oil products demand for the whole state (462PJ/year at 2005) It should be noted that petroleum products are distributed nationally and Australia is a net importer of oil. It is entirely likely that there is some imported component to transport fuel sales in Melbourne though that fraction will depend on global demand and supply and currency exchange rates.

Facing the future

However comfortable the current energy supply situation is, there are possibly some dramatic changes ahead in the long term

Recent scenario analyses by CSIRO (Foran and Poldy 2002; Schandl et al. 2007) show how Australian and particularly Victorian gas and oil reserves are likely to become uneconomical within the next 50 years. There is the time and potential for cities to adapt and potentially benefit from such changes but if current drivers and patterns of oil consumption persist, then there will undoubtedly be a sudden realization of the limits to resources.

The supply of brown coal has greater longevity with one estimate suggesting that there are 550 years of economic reserves (CSIRO 2006). The limiting factors for coal powered electricity are investment in generation capacity and greenhouse gas (GHG) emissions. In 2002 the Victorian Infrastructure Planning Council completed a review of Victoria's future infrastructure needs and made these statements (IPC 2002):

"Victoria's current energy supply is not sustainable on environmental, social and economic grounds. The national electricity and gas networks must operate in a more versatile and responsive way and supply sources should be diversified if Victoria's future energy needs are to be met in 2020 and beyond…"

"Victoria's generation capacity is currently around 8765 MW, but up to 2500 MW of new capacity is required by 2012–13 to meet demand projections"

As at 2008 Victoria's electricity generation capacity is still around 9000 MW with another 550MW of non-renewable and 606MW of renewable generation projects planned (Penney et al. 2008). (Currently the cost per MW of renewable generating capacity is close to twice that for non-renewable).

It would appear that current capacity may already be showing signs of strain. A recent heatwave resulted in extreme demand for electricity in Melbourne, producing prolonged blackouts occurring over large areas of the city, affecting residents, disabling transport and communications systems (O'Keefe 2009). Although this may be an isolated incident, it is worth noting that it occurred because of a heatwave at a time of year which is increasingly becoming the peak season for electricity demand. Not only is there the question of limited capacity but there's also the concern that infrastructure installed in the past may not be able to function at such high loads at the hottest time of year.

[γ] calculated assuming 1 barrel of oil equivalent (boe) equals approximately 6.1 GJ

The future demand for energy by Melbourne will be strongly coupled to its total population. At the last census this was 3.6 million but that is forecast to increase to 5 million by 2030 (DPCD 2008b). It is an open question as to whether the per capita requirements for energy will continue to increase as they have done for the last 50 years or whether we will see them plateau or even decrease. With the increasing reliance on appliances and particularly air conditioners, there are forecasts for energy use in the residential sector to grow by 35% by 2020 (relative to 2005 levels). Given the recent experience of peak electricity demand moving to the summer season, this is likely to be exacerbated by climate change. Simultaneously the forecast is for energy consumption in the industrial sector to increase by 26%, and in the commercial sector by 54% (SEAV 2005).

According to the recent planning document *Melbourne@5million*: "In 2006, 1.86 million people had jobs in Melbourne. This is expected to grow to nearly 3 million by 2036.Most of these jobs are located in central and inner Melbourne" (DPCD 2008a).

The Australian Bureau of Transport and Regional Economics (2007) has produced projections that Melbourne's road freight transport task will also increase by 54% (relative to 2005 levels) to 17 billion tonne-kilometres and that total vehicle kilometres travelled in the city will rise 30% by 2020 see Figure 11.

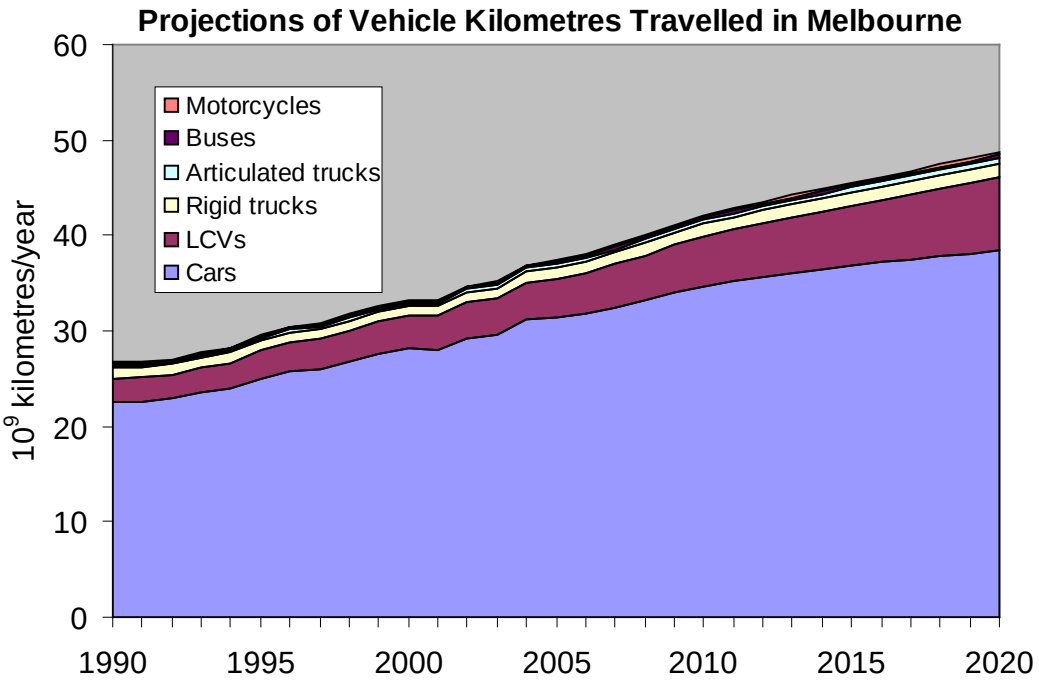

Figure 11. Base case projections of vehicle kilometres travelled by type of vehicle for Melbourne, 1990–2020 (data from (BTRE 2007))

Having identified several urban energy issues it is surprising that Australian cities generally lack a dedicated metropolitan level of governance that would be a natural locus for urban energy policy (or, for that matter, urban energy statistics). Many policy controls such as renewable energy targets and carbon pricing/taxes are imposed through legislation and regulation at a State or National level. Since each state has

only one major urban area, the State level urban policies are effectively the policies for the main city, in Victoria this is Melbourne.

Governments at all levels are attempting to defy some of aforementioned projections and make a transition towards more energy efficient/low carbon cities through a number of initiatives that include:

- energy sensitive urban planning
- investing in low-carbon or renewable energy infrastructure
- institutional and economic incentives
- promoting alternative transport modes

We briefly discuss a few examples of the above though we note this is not an exhaustive list. There are, for example, important connections between food production, food supply and energy (Larsen et al. 2008).

Energy sensitive urban planning

In 2002 the Victorian Government released a strategic planning document for Melbourne: *Melbourne 2030* (DOI 2002). Two key features of the strategy were an urban growth boundary (UGB) and the creation of a multi-centre city through six new Central Activities Districts. Part of the intent was to contain the spread of Melbourne, provide alternative locations to the centre of the city for work and other activity and thus reduce much of the (energy) costs associated with transport. Employment corridors have been proposed that would link activity centres, education, research and medical precincts, and areas with high employment.

The original strategy was always intended to be a 'living document' and after some degree of public scrutiny it has undergone revision and is now supplemented with other strategic plans (Planning for All of Melbourne 2008). The UGB has been compromised to accommodate some of the 284,000 new dwellings expected to be built in growth areas and to maintain housing affordability. Some plans for activity areas have met with resistance from residents who do not want to see such development in their area.

It would not be wise to conclude that the expansion of Melbourne's area and the decrease in residential densities is directly responsible for increased residential energy requirements. Newman and Kenworthy (1999) emphasised the perils of urban sprawl while Troy (2006) has highlighted, with equal vigour, many negative issues associated with urban consolidation. It is important to underline that lower density living, of itself, does not necessarily lead to a greater energy impost on society. If, as in the *Melbourne 2030* plans, the urban area is punctuated by local centres of business and activity then there is every opportunity to realize a lower energy configuration of the city. However, low-density urban forms that accommodate more residents who each require more travel will necessitate higher energy demands.

There are designs for the re-population of the city centre: several high density residential buildings have been constructed on land that was previously inner-city docklands and the new City of Melbourne Council House, referred to as "CH2", and the Exhibition Centre are demonstrations of energy conscious construction and operation of public buildings.

A key direction of current energy policy is in energy efficiency and demand management particularly in buildings, appliances, industrial processes and transport systems. One possible initiative is smart metering whereby more information can be gathered about how much energy is used, for what purpose and when, allowing for better targeted regulations and financial controls.

Investing in low-carbon or renewable energy infrastructure

Decisions made decades ago about the installation of coal-fired generating capacity have locked in a dominant industry of mining and using brown coal in Victoria. One response has been to prioritise research on carbon sequestration technologies but even proponents of these recognise that it will be some decades before this can be made operational. There are, however, alternatives that have already been implemented.

In the financial year 2000-01 Melbourne Water consumed 330GWhr of energy for all purposes but through generating electricity from biogas at a treatment plant they were able to generate 100GWhr for their own operations and choose to sell another 29GWhr back to the grid.

As shown in Table 6, much of the recent investment in generation plant is in the form of gas or renewable energy. It is also evident that a number of electricity generators are embedded, that is, they are connected to the distribution network but supply power close to the community, business or industrial area. Distributed power has significant advantages in energy efficiency and there are at least 40 planned or existing distributed power projects across Victoria.

Institutional and economic incentives

At both the national and state level there is financial support for solar power. Up until recently residents could get a rebate for purchasing solar panels or solar hot water heaters. This has been partially replaced with a scheme of tradeable credits for solar generated power. Solar credits are based on the amount of electricity displaced. From July 2006 Victoria has had regulations requiring a solar water heater or a rainwater tank on all new houses.

Major energy companies have mandatory renewable energy targets (MRET) which require them to provide a certain fraction of the energy they deliver from renewable sources. So far the level of MRETs have been relatively modest (~5%) but the State Government of Victoria currently sources 10% of its energy needs from green power with plans to increase this to 25% by 2010 (see here) and most residents in major Australian cities have the choice of getting all their electricity from renewable sources. There is the possibility of a market driven increase in renewable energy generation depending on how the Australian Federal Government implements carbon pricing in 2010 (Brain and Armstrong 2004; Garnaut 2008).

Indeed, there has already been an interesting effect from the deregulation of the energy industry, the establishment of the National Electricity Market (NEM) and a particularly hot summer in 2000-01.

For most of the last 50 years electricity had been generated and supplied by a centralised authority: the Victorian State Electricity Commission. In 1994, the

Commission was disaggregated into five distribution and retail companies, five generation companies and one transmission company. Along with the Gas and Fuel Corporation of Victoria, these businesses were all corporatized then privatised between 1995 and 1999. This institutional disaggregation may result in genuine efficiencies from competitive energy markets but it also means that there are fewer large players able to make the substantial investment in new coal-fired generation.

Over this same period the NEM was initiated and the retail market for electricity became much more fluid and heterogeneous. During the hot summer of 2000-01, high spot and contract prices for electricity triggered investment in new generators. However, most of the generation technologies that could be afforded, and quickly, by the generation companies were gas powered. Even so, the generators were not completed in time for the following summer (DNRE 2002).

In summary, new renewable energy targets, regulations and new institutional arrangements may actually encourage low carbon, energy efficient or renewable power generation although we may anticipate supply to follow demand as commercial enterprises are often reticent to invest in new infrastructure until after they receive signals from the market.

Promoting alternative transport modes

Melbourne has retained an enviable tram system and although this has been maintained it has not increased commensurately with the expansion of the city apart from a recent extension to the Docklands area where there has been much residential development. There has been an increasing commitment to cycling culture since 2002 and, like the longstanding mobility strategy of Copenhagen, the City of Melbourne has developed long term plans for making the inner city more available to pedestrians and cyclists (Melbourne 2007). There is also a proposal for a new a North-South underground mass transit project (City of Melbourne 2006) but a core feature of the transport strategies at both the inner city and metropolitan levels is one of improving networking: enabling people to use the various modes of the public transport system more easily and more efficiently and perhaps to use active personal transport (cycling, walking) more often.

The urban form of Melbourne has transport and therefore energy consequences and the current urban area, defined by the stock of dwellings, buildings and roads will be around for many decades to come. Over the next 20 years, the city may well see the impact of peak oil on personal mobility but to retain the vitality and function of the city, it may be the case that more public transport, intelligent networking and active personal transport will be required.

Conclusion

We have presented data concerning the long-term energy history of Melbourne. This is useful both to observe long-term changes to urban metabolism and as a companion to the socio-economic history of the city. The energy future of the city is dependent on a number of intersecting factors including population, urban lifestyle, urban form, current and alternative energy supply. Efforts at reducing the energy and carbon intensity of Melbourne in the near to medium term will be hampered by legacies of past infrastructure choices and of the increasingly affluent urban lifestyle to which we have become accustomed. At the metropolitan level, there is the opportunity to

depress the trajectories of increasing per capita energy consumption and realize a lower carbon city through strategies that include energy conscious urban planning, investment in renewable or low carbon electricity generation, encouraging active and public transport and, at a national level, imposing a cost to carbon.

Appendix: Notes on Methods

Many of the data sets obtained in this study were only available at the state level and the data shown for example in Figure 9 is derived. The derivation of the data on energy use by industries used the fraction of land occupied by different sectors in Victoria, that occurs within Melbourne statistical division after subtracting the land occupied major energy users outside of Melbourne e.g. Aluminium smelters in Portland and Port Henry. This fraction was then applied to the state level statistics on energy use by sectors after also subtracting the energy use by major energy consumers outside of Melbourne

Often data about bulk energy demand or supply was available from 1961 but detail on the end-use was only available from 1973. We have resisted the temptation to extrapolate backwards though further research may reveal deeper historical trends.

There is a need for more collection of data specifically about the city though the difficulty of this is exacerbated by the privatisation and disaggregation of the energy supply industry in Victoria and the different jurisdictions of utilities and governance.

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