Greenhouse Gas Emissions in Australian Transport 1900 and 2000

Occasional Paper

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GREENHOUSE GAS EMISSIONS IN AUSTRALIAN TRANSPORT IN 1900 AND 2000

Dr. Leo Dobes

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FOREWORD

In his 21 December 1992 Statement on the Environment, the Prime Minister announced that the Bureau of Transport and Communications Economics (BTCE) would provide a comprehensive analysis of the range of possible measures for reducing greenhouse gases in the transport sector.

Base case estimates of greenhouse gas emissions from the transport sector to the year 2015 were published in March 1995 in BTCE Report 88, *Greenhouse Gas Emissions from Australian Transport: Long-term Projections*. Work is continuing within a Branch headed by Dr Leo Dobes on estimating the cost to the community of implementing a range of measures to reduce emissions.

In order to gain a historical perspective on greenhouse emissions from the Australian transport sector, Dr Dobes has estimated emissions in the year 1900 and contrasted them with BTCE projections for the year 2000. The views expressed in this paper are his own, and should not be attributed to the Department of Transport or the BTCE.

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Dr M Haddad
Director

Bureau of Transport and Communications Economics
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ABSTRACT

Comparable figures are provided for the first time on emissions of greenhouse gases from the Australian transport sector in 1900 and 2000. Greenhouse emissions from the transport sector increased ten-fold during the twentieth century, but Australia's population has increased five-fold, and real GDP 23 times, while urban densities are now only about one third of those in 1900. Within the limits of long-term historical comparisons, it is concluded that use of the internal combustion engine itself has not contributed disproportionately to greenhouse emissions in the transport sector. However, electric vehicles would have been better.

CHAPTER 1 INTRODUCTION

Transport externalities are not a new phenomenon.

To reduce congestion, Julius Caesar in 45 BC declared 'the centre of Rome off limits between 6 am and 4 pm to all vehicles except those of officials, priests, high-ranking citizens, and visitors'. The Roman poet Juvenal complained in the year AD 100 that he was unable to sleep because of the noise of cart wheels on stone paving. In the year 1900 in New York 'horses each day created 1,100 tonnes of manure, 270,000 liters of urine, and 20 carcasses'. London 'had an active Horse Accident Prevention Society in the late nineteenth century' and 'New York was averaging four pedestrian fatalities and forty injuries a week due to horse traffic' in 1867 (Lay 1993, pp. 176, 132).

The stench and bacterium-carrying dust composed of dung have been replaced by noxious emissions such as carbon monoxide and volatile organic compounds. Modern motor vehicles generate noise, congestion and accidents, just as horse-drawn vehicles did. Clearly, some early views of the car as an environmental saviour have not been sustained; only the nature of the problem has changed.

In recent years there has been mounting concern about the contribution of the transport sector to global warming. This concern raises the question of whether the motor vehicle has not only failed to eliminate externalities such as congestion and noxious emissions, but whether it has also exacerbated the greenhouse effect. The commonly held view appears to be that it has.

Emissions from fossil-fuelled motor vehicles, ships and aircraft are composed mainly of carbon dioxide, a direct greenhouse gas. Animals produce methane and nitrous oxide. But methane has a 100-year Global Warming Potential (GWP) 24.5 times that of carbon dioxide, and nitrous oxide has a GWP of 320 relative to an equal mass of carbon dioxide (IPCC 1994, p. 28). Given these large differences in GWPs of emissions, the question is essentially whether the age of the motor vehicle is more, or less, 'greenhouse-friendly' than the more romantic era that preceded it.

An ideal, controlled experiment between an economy with motor vehicles and its twin without them is obviously not feasible. A second-best option of comparing greenhouse emissions in the year 1900 (the pre-motor vehicle age in Australia) and those in the year 2000 has therefore been adopted in this paper.

Inadequate data on the size and scope of the transport task in 1900 precludes comparison with the year 2000 on a standardised basis. Emission levels for the two years are therefore compared by allowing for major demographic and economic changes over the century; providing a rough 'with and without cars' perspective. Emissions in the year 2000 are estimated on the counterfactual basis that electricity rather than gasoline achieved dominance over animals and steam in the transport sector.

CHAPTER 2 AUSTRALIAN TRANSPORT IN THE NINETEENTH CENTURY

Australian transport development in the nineteenth century is often characterised by its role in the conquering of distance; along the lines of Blainey's (1966) thesis that distance shaped Australian history. Analysis at successively deeper (almost quasi-fractal) levels, however, suggests that the transport sector was also subject to rapid technological change in an evolutionary drive for increased speed and efficiency.

Only seven horses, seven head of cattle and assorted pigs, poultry and rabbits landed with the First Fleet in 1788. Walking and the 'saltwater highway' were initially the major forms of transport. Only the rich could afford horses in the nineteenth century. In rural areas in particular, walking was the main means of both personal and goods transport. According to Kennedy (1986, p. 82), human porters carried about 18 to 23 kg and moved at 3 to 8 km an hour. Fitzpatrick (1980, p. 173), also points out that

> the bicycle was probably more important and more intensively used for transport on the Western Australian goldfields than in any other rural area of the world in the 1890s...In addition to written material, the most striking evidence lies in photographs.

Forty draught oxen were landed in 1793 (Jervis 1959, p. 221), and oxen came to be used increasingly as government and private herds grew in the early nineteenth century. Bullock teams initially dominated horses in overland haulage because the capital costs of establishing a bullock team were significantly lower; and bullocks could forage for grass whereas working horses required fodder which itself required (expensive) transport (Kennedy 1986, pp. 187–202).

As fencing of farms reduced access to free grass for bullocks, as fodder became more generally available, and as road building progressed, horses began to dominate. Bullocks required cueing (metal shoes) before they could use formed 'metalled' roads. The greater strength and speed of horses was particularly important; and Kennedy (1986, p. 221) points out that where seasonal patterns required rapid transport (for example, to deliver wool to riverboats before the rivers fell) horses replaced bullocks. Bullocks nevertheless continued to be used in remote areas even during the early years of the twentieth century.

With the large influx of gold diggers from the 1850s, animal power became relatively scarce. From 1853, steam-driven paddlewheelers began to transport goods such as flour, wool, fencing wire and general supplies to the towns and stations along the Murray–Darling and Murrumbidgee river systems. (Contemporary accounts also record the integration of riverboats with camel teams: (Godson 1973, p. 35). Ultimately, about 6500 km of waterways were opened to shipping, albeit on a highly seasonal basis. Railheads such as the port of Echuca allowed quick transport of pastoral output to capital cities. Steamers and ferries were also used on the larger coastal rivers such as the Hawkesbury, Hunter, Clarence and Shoalhaven in NSW; the Yarra in Victoria; the Derwent and Tamar in Tasmania; and the Swan in Western Australia.

Railways displaced animals in the second half of the nineteenth century, particularly on long distance routes. However, horse and bullock teams subsequently formed new transport networks to supply the railheads and loading points along rail lines. Rail also made available cheaper fodder in towns, permitting an increase in the number of animals. In order to capture trade that was being lost to riverboats carrying wool to South Australia and Victoria, NSW pushed its railway network westward to the Darling, and southward to the Murray and Murrumbidgee. As late as 1893, however, the NSW policy was seen as having been only partially successful. Despite subsidised rail rates, riverboats continued to hold their own when the rivers were navigable (Coghlan 1893, p. 141).

Apart from their speed, the significant advantage of the railways was their reliability. In the nineteenth century, railways were the only land transport mode that was not subject to the vagaries of the seasons. By 1900, almost 22 000 km of private and government railway lines were open to traffic.

Steam ships replaced sail fairly rapidly in the late nineteenth century, particularly with the setting up of a network of bunkering stations (Burley 1960, p. 396). In 1876, for example, only 44 per cent of ships entering ports in New South Wales were steam-powered. By 1900 the proportion was 80 per cent, and 96 per cent by 1913 (*Official Yearbook of NSW* 1914, p. 299). Other, less successful technologies were also tried. Portus (1904, p. 188) recounts the introduction in 1835 of a passenger ship powered by horses (the aptly named 'Experiment') to carry passengers between Sydney and Parramatta. The mechanics are not explained, but the concept was apparently not popular with passengers, so an engine was installed.

As pastoral activity expanded into the more arid parts of Australia in the late nineteenth century, camels (dromedaries), as well as donkeys and mules, were used for mining and pastoral freight because of their ability to forage from the land. The carrying capacity of camels was increased substantially in sandy areas in the late nineteenth century by hitching them to wagons. However, motor vehicles had all but replaced camels, donkeys and mules by the 1930s just as they had replaced horses and bullocks.

At a deeper level still, there was competition even within modes. Bullocks and camels could be castrated as young bulls or later in life to permit them to grow to a larger size and to increase in strength. Early drays of about two-and-a-half-ton capacity were gradually fitted with wider tyres as roads improved, and had increased in size to five tons by the 1860s. They were replaced by wagons of increasing size up to a typical carrying capacity of about 15 tons during the 1860s, and by 20 ton 'Table Top' wagons in the 1890s. Horse-drawn vehicles from wagons to coaches also improved significantly during the century; and stronger, larger horses such as Clydesdales and Percherons were gradually imported and used according to local conditions. Kennedy (1986) and McGregor (1981) provide various examples.

Riverboats, railway locomotives and steamships also became increasingly specialised, particularly with the development of the steam engine and the use of higher pressures and multiple cylinders.

CHAPTER 3 GREENHOUSE EMISSIONS IN 1900 AND 2000

Greenhouse emissions by major transport mode in the year 1900 are shown in table 1. These estimates appear to be the only available historical data for Australia.

Because of the paucity of historical information it was necessary to make (often arbitrary) assumptions in table 1 in areas such as the degree of forest regrowth in the provision of firewood to riverboats, and the numbers of working animals and their specific employment. Coastal shipping is probably the transport mode least reliably estimated because of the absence of any official statistics on domestic ship bunkers. Explicit omissions from calculations in table 1 include factors such as rotting animal carcasses, mechanised harvesting of fodder (as part of full fuel cycle estimates of animals), and emissions by ferries. Even the Global Warming Potential (GWP) factors used to convert emissions to CO_2 equivalents in any inventory of greenhouse gases are subject to uncertainties of plus or minus 35 per cent (IPCC 1994, p. 4). It is important therefore to focus analysis more on the order of magnitude of the estimates than on the absolute level of individual numbers.

Coal-burning railways and steamships accounted for more than three quarters of CO_2-equivalent emissions from domestic transport in 1900. Emissions from animals accounted for only about a quarter of total greenhouse emissions, putting them on a par with steam locomotives. Emissions from wood-burning riverboats were comparatively low, but the transport task that they performed was limited to the Murray–Darling river system.

Coastal shipping was itself the source of over half of all greenhouse emissions in 1900. Although the figure for steamships is high, it is not inconceivable. As pointed out by Davison, McCarty & McLeary (1987, p. 94), the sea was more of a 'ring road' than a border in the nineteenth century. Davison et al. also reproduce (p. 76) Tom Roberts's painting 'An autumn morning at Milson's Point', depicting a murky scene on Sydney harbour. The caption underneath reads 'this ... study, painted during the artist's visit to Sydney early in 1888, reminded an Age [Melbourne newspaper] reviewer that '[Sydney] is a city consuming fossil fuel and not charcoal'.

TABLE 1 GREENHOUSE GAS EMISSIONS[a] FROM AUSTRALIAN TRANSPORT IN 1900

Mode	*Energy Consumed (GJ)*	*CO_2 (Mg)*	*CO (Mg)*	*CH_4[b] (Mg)*	*NO_x (Mg)*	*N_2O (Mg)*	*CO_2 equivalent[c] (Mg)*
Rail	17 625 576	1 525 000	3 254	476	3 828	978	1 883 500
Tram	2 521	216	0.468	0.024	0.567	0.142	267
Riverboat	361 550	24 215	69	5	11	1	24 815
Draught horse[d]	8 165 415	-	-	19 840	-	112	521 920
Harness horse[d]	7 405 120	-	-	22 022	-	0	539 539
Saddle horse[d]	9 237 785	-	-	25 251	-	215	687 450
Camel	193 815	-	-	487	-	2	12 572
Donkey/ mule	16 060	-	-	40	-	0.3	1 076
Bullock	190 530	-	-	441	-	3	11 765
Steamship (dom)	38 976 894	3 332 524	7 238	790	8 760	2388	4 193 357
Intern. coastal	3 101 640	265 190	576	63	697	190	333 686

TABLE 1 GREENHOUSE GAS EMISSIONS[a] FROM AUSTRALIAN TRANSPORT IN 1900 CONTINUED

TOTAL AUSTRALIA	85 276 906	5 122 954	11 069	69 415	13 286	3 889	8 185 459
intern. steamship	267 005	2 282 900	4 959	542	6 001	1 636	2 872 666

a. Means that there were no emissions, or that GWPs were unavailable. Zero (0) means that emissions were too small to record. Rounding errors may mean that totals do not always match sums of rows or columns. GJ = Gigajoules = 10^9 joules. Mg = Megagram = 10^6 grams.

b. Includes estimated fugitive CH_4 emissions from coal seams during mining for railways, trams and steamships. It is not known where coal was sourced, and specific CH_4 emission factors are not available. Using the methodology in NGGIC (1994d), it was therefore assumed that all coal for each mode was sourced at one Class B (non-gassy) black coal mine.

c. 100-year horizon Global Warming Potentials (GWP) used per Mg of gas were 1.0 (CO_2, carbon dioxide); 1.0 (CO, carbon monoxide); 24.5 (CH_4, methane); 8 (NO_x, oxides of nitrogen other than N_2O); 320 (N_2O, nitrous oxide); based on IPCC (1990, pp. 11–13; 1992, pp. 19–21; 1994, p. 28). IPCC (1994, p. 27) points out that GWPs are 'calculated on the assumption that present background atmospheric composition remains constant indefinitely. An assumption of increasing CO_2 concentrations, which would lower the additional forcing of incremental CO_2 emissions, would increase the GWP of other gases relative to CO_2'. From this perspective, it is possible that GWPs for gases such as CH_4 are overstated for 1900, when atmospheric concentrations of CO_2 were lower than at present.

d. Includes an allowance for horses used to produce fodder for transport animals (based on proportion of fodder grown to total acreage of crops).

Sources Appendixes I to IV.

TABLE 2 GREENHOUSE GAS EMISSIONS FROM THE AUSTRALIAN DOMESTIC CIVIL TRANSPORT SECTOR IN THE TWENTIETH CENTURY

(Gigagrams of CO_2 equivalent[a])

Mode	1900	1988	2000
UNADJUSTED			
rail[b]	1 884	3 886	4 421
riverboat	25	0	0
animal	1 774	0	0
coastal ship[c]	4 527	3 405	2 011
motor vehicle[d]	0	68 051	75 164
aircraft	0	4 565	5 990
total	8 210	79 907	87 586
PER CAPITA			
population[e] (millions)	3.8	16.5	19.0
rail	496	236	233
riverboat	7	0	0
animal	467	0	0
coastal ship	1 191	206	106
motor vehicle	0	4 124	3 956
aircraft	0	277	315
total	2 161	4 843	4 610
GDP ADJUSTED			
real GDP[f]	21.0	342.6	481.1
rail	90	11	9
riverboat	1	0	0
animal	84	0	0
coastal ship	216	10	4
motor vehicle	0	199	156
aircraft	0	13	12
total	391	233	181
ADJUSTED FOR URBAN DENSITY			
urban density factor[g]	144	55	55
rail	1 884	3 107	3 772
riverboat	25	0	0
animal	1 774	0	0
coastal ship	4 527	3 405	2 011
motor vehicle	0	40 328	45 581
aircraft	0	4 565	5 990
total	8 210	51 405	57 354
INTERNATIONAL			
ship	2 873	2 192	2 571
air	0	3 527	7 004
international total per capita	756	347	504
internationbal total per GDP	137	17	20

a. Figures for 1988 and 2000 converted to full fuel cycle values on the basis of tables 3.6 and 6.1 in BTCE (1995) to ensure comparability between modes, and with 1900. (Air, ship, non-electric rail and motor vehicle emissions were multiplied by 1.11. This may result in some distortion for non-CO_2 emissions, but it is not considered significant.) It was not possible to calculate full fuel cycle equivalents for each mode in 1900, but total emissions are roughly full fuel cycle estimates; animal numbers, for example, include those used to produce fodder. Gigagrams (Gg) = 10^9 grams.

b. Figures include trams. Emissions in CO_2 equivalents for trams were 0.222 Gg (table 1) in 1900 and were estimated at about 60 Gg in each of 1988 and 2000 on the basis of IPCC/OECD (1994, p. 144), Apelbaum (1993, p. 92) and Armour and Jordan (1992, p. 9).

c. Does not include ferries.

TABLE 2 GREENHOUSE GAS EMISSIONS FROM THE AUSTRALIAN DOMESTIC CIVIL TRANSPORT SECTOR IN THE TWENTIETH CENTURY CONTINUED

d. Includes cars, buses, trucks, light commercial vehicles, and motorcycles. Emissions in CO_2 equivalents for buses is estimated at 1 112 Gg and 1 409 Gg for 1988 and 2000 respectively, and 334 Gg in each year for motorcycles (ABS 1992; BTCE 1995; BTCE estimates).

e. Figure for 2000 is for the medium fertility, low immigration 'A and B' scenario (ABS 1994b, p. 48), consistent with population forecasts used for passenger vehicle emission forecasts in BTCE (1995).

f. In $Aust billion ($10^9$), current price figures deflated by the GDP(E) deflator, with 1989–90 = 100. Figure for 2000 extrapolated from 1993–94 real GDP, assuming annual growth of 3.2 per cent to 1997–98, and 3.3 per cent thereafter, consistent with assumptions by BTCE (1995) for long-term forecasts for the Australian economy.

The Australian Bureau of Statistics uses the income, expenditure, and production approaches to measure GDP, giving GDP(I), GDP(E) and GDP(P) respectively. GDP(E) has been used in table 2 because data for 1900 were available only on this basis and because the deflator is based on the same approach.

g. Estimates of urban emissions generated by rail and motor vehicles in 1988 and 2000 are given in table V.2 (appendix V). A weighted urban density factor developed in table V.1 was used to scale down (by 55/144) the urban component of rail and motor vehicle emissions in 1988 and 2000 to provide comparability with urban densities in 1900.

Sources

. emissions in 1900: table 1.

. emissions in 1988 and 2000: BTCE (1995)

. population in 1900 from Official Year Book of the Commonwealth of Australia 1901–1907, (1908, p. 171); other years, ABS (1994a); year 2000, ABS (1994b).

. GDP (gross domestic product) in current prices and GDP(E) deflator for 1901 obtained from Maddock and McLean (1987, pp. 359–61); GDP for 1987–88 to 1993–94 obtained from ABS (1994c, table 58); figure for 2000 extrapolated from 1993–94 consistent with BTCE (1995): see note f. above.

. urban density estimates taken from appendix V.

Table 2 provides a comparison of greenhouse emissions from the transport sector in the year 1900 with emissions in 1988 and 2000. Emissions for each of the three years are expressed as far as possible on a full fuel cycle basis: that is, as emissions from the fuel consumed during the actual activity of transportation, as well as from energy used to extract, process and distribute the fuel to end users.

IPCC/OECD (1994, p. 1.11) recommends that, for informational purposes, international bunker fuels should be subtotalled separately in national inventories of greenhouse emissions. Emissions due to air and maritime fuel uplifted in Australia have therefore been recorded separately at the end of table 2, rather than being attributed to domestic Australian emissions. It is interesting to note that emissions per head from international ship and air bunkers combined were roughly 50 per cent greater in 1900 than in 2000. Adjusted for increased real GDP, however, greenhouse emissions from international bunkers have decreased almost sevenfold.

As might be expected, total domestic emissions in the year 2000 are an order of magnitude greater than those in 1900. The dominance of the motor vehicle is also of little surprise. Emissions from coastal shipping, however, show an absolute decline. This is probably partly due to improved thermal efficiencies of engines, but the main effect is the switch of domestic freight transport to rail and road, as well as passengers to air transport.

Because it is the anthropogenic Greenhouse effect that is relevant, differences in the (human) population need to be taken into account in any historical comparison. Adjustment for population levels results in a per capita level of emissions in 2000 that is only just over two times that of 1900, whereas the unadjusted level is more than 10 times that of 1900. Clearly, population growth is an important factor in explaining increased greenhouse emissions in the Australian transport sector over the last 100 years or so.

The amount of freight and the distance that it was transported will have changed significantly because of increased specialisation in the Australian economy. The processing of goods at more than one location and their ultimate transport to distant markets, encouraged partly by lower freight rates, will have increased with economic growth. Pizza delivery, courier and other services requiring transport have also grown. Increased national income thus reflects the greater range and volume of commodities and services transported, particularly in the latter half of the twentieth century.

The long-term increase in real GDP has also permitted the rise of discretionary or recreational travel as well as increased levels of ownership of personal transport means such as motor vehicles. Discretionary travel, already on the rise early in the century, was referred to quaintly as the 'travelling habit' in the *Report of the Board Appointed to Investigate the Problem of Relieving Congestion of Traffic in Melbourne* (1919, p. 3):

> The principal causes of the congestion of street traffic in portions of the City proper are the growth of population, the increase of what has been termed the 'travelling habit' of the people, and the greater volume of vehicular traffic induced by the expansion of the City's commercial and industrial activities.

On the other hand, increased national income has fostered the use of telecommunications in Australia. In 1900, riverboats relied on telegraphed information of woolclips and river levels. Steamships and railways also used electrical energy to coordinate freight and passenger movements. Modern telecommunications have permitted better coordination of freight (goods deliveries to retail outlets or to customers are made only when required), but just-in-time production methods may have increased the overall number of trips. However, the almost universal availability of telecommunications in recent years has enabled it to become a significant substitute for passenger transport (although this substitution has in part only been a shift from letter mail to telecommunications).

The effect of allowing for changes in economic activity is illustrated in table 2, where emission levels have been adjusted for differences in real GDP. Even when the usual problems of such long-term comparisons are taken into account, the result is still remarkable. (Some of the decrease in transport sector emissions relative to real GDP is probably due to the growing share over the century of that part of the service sector that does not utilise transport inputs intensively.) Per unit of GDP in real terms, domestic transport emissions will have declined in 2000 to almost half their level in 1900.

While domestic transport emissions will have grown about 10 times since 1900, living standards (real GDP per capita) will have increased only 4.6 times by 2000. Transport emissions have thus grown about twice as fast as living standards during the twentieth century. On an admittedly simplified interpretation of this figure, it is nevertheless arguable that even a substantially lower historical level in living standards would not itself have reduced significantly the level of transport-related emissions of greenhouse gases in the year 2000. The corollary of this proposition is that reductions in living standards alone would not be a particularly effective means of reducing emissions in the transport sector.

It is likely, however, that trip distribution patterns will have changed over 100 years, particularly with the growth of lower density suburbs around cities.

Adjustment for relative urban densities is fraught with difficulty because of historical inconsistencies in the statistical specification of urban areas. A single-figure measure of urban density can only be an approximate representation of a whole city. No forecast of urban density appears to be available for the year 2000, and the same value (based on the 1991 census) has been used in table 2 for both 1988 and 2000. Nevertheless, the urban component of transport emissions for 1988 and 2000 has been adjusted in table 2 to reflect the fact that Australian metropolitan densities in 1900 were more than double those of today.

While increased population density alone is not a sufficient condition for reduced urban travel, it is arguable that a significant change in density is likely to affect modes of transport and travel patterns. For example, walking and bicycling were common modes of passenger transport in 1900, and freight would not have needed to move as far within the more compact cities of the time. Whether the same would be true in equally compact but motorised cities is debatable, but the figures in table 2 have been adjusted on the basis that increased urban densities are reflected directly in decreased emissions. The adjusted figures therefore represent the best possible outcome from increased densities.

The result indicates that total greenhouse emissions in 2000 could be reduced to two-thirds of their currently projected level if Australians lived in cities populated about two and a half times more densely than today. However, this is likely to be an upper bound estimate of potential reductions in emissions. It assumes availability of transport alternatives to the motor car (including walking), as well as corresponding changes in the 'travelling habit' of the population.

Technical progress occured both in terms of substitution of technologies (eg cars for horses) and in improvements within technologies through increased thermal or mechanical efficiency (ratio of power output to energy input). Because of the conceptual difficulties in comparing technologies as different as camels and aircraft, no adjustment has been made for technological substitution. Indeed, it is precisely the effect of technological substitution that is being examined here.

Taking into account today's lower urban densities and higher levels of economic activity and population, it is arguable that transplanting today's transport system to the year 1900 would have improved greenhouse emissions, despite the replacement of animals and steam by the internal combustion engine. It needs to be recognised, however, that no allowance has been made for broader structural change in the economy. A more cautious conclusion might therefore be that transport-related greenhouse emissions would not have been significantly less today even if the motor car had not been invented.

CHAPTER 4 ELECTRIC VEHICLES IN THE YEAR 2000: BACK TO THE FUTURE

An alternative perspective can be gained by applying a counterfactual: what would domestic greenhouse emissions have been without the internal combustion engine?

A three-wheeled 4.8 km/h steam-powered cannon wagon was produced in 1769 in France and a steam-powered carriage in 1801 in England. Electric cars and locomotives were made in England in the 1830s. In 1900 the French B.G.S. Electric Car held an electric vehicle distance record of almost 290 km per charge, and a Belgian vehicle attained a world speed record for automobiles of 105 km/h in 1899. Of the cars manufactured in the United States in 1900, 1575 units were electric, 1684 were steam-driven and only 936 were gasoline powered. (IEA 1993, ch.1; Shacket 1979, ch.1).

Lack of electricity in rural areas, and the limited range of electric vehicles and steam vehicles (which required 10 minutes to start), coupled with development of electric starter motors for gasoline cars and the low-priced Model T Ford, ensured the dominance of the internal combustion engine from the mid–1920s. Arthur (1989, p. 127) quotes a contemporary assessment from 1904 predicting that steam would win out over the inconvenience of gasoline vehicles, but points out that 'a series of trivial circumstances pushed several key developers into petrol just before the turn of the century and by 1920 had acted to shut steam out'.

Probable developments over the course of the century require some speculation. However, detailed speculation may not be necessary if we accept the thesis of a high degree of similarity in logistic development noted in a wide range of social phenomena by Marchetti (1986, 1991). Using the same approach as Marchetti, Nakicenovic (1987, p. 317) identifies two separate exponential 'pulses' in the growth of motor vehicle fleets: 'the first characterises the substitution of horse-drawn road vehicles and the second the actual growth of road transport at large'.

If the thesis proposed by Marchetti and Nakicenovic is correct, then it is likely that the growth in usage of motor vehicles over the twentieth century could have been substituted by a similar pattern of growth by electric or steam vehicles or some other mode determined by historical circumstances. It can simply be assumed that the replacement of one transport mode or technology follows the same growth pattern as the replacement of a different mode at a different time in history.

It is arguable that shared infrastructure and a more even base load demand meant that there were significant potential cost advantages to be reaped from economies of scope in supplying electricity at street outlets. Capital cities and country towns such as Tamworth in NSW had already begun in the 1880s to provide an electricity grid for street lighting, tramways, and supplies to homes and factories. In Victoria, regional centres like Ballarat and Bendigo had electric trams by 1905. Lincolne (?1954, p. 29), writing about the Melbourne Electric Light and Traction Co. in about 1905, notes that:

> About this time the electric motor car was introduced and, as another source of revenue a scheme was prepared for the installation of charging stations using Nodon valves in rectifiers. [But] this scheme did not advance very far.

It is not unrealistic to assume that relatively rapid reductions in unit costs would have produced conditions sufficient to foster 'take-off' and then 'lock-in', at least in urban areas or their vicinity in the first half of the century. In urban areas, economies of scope between car recharging stations and electricity supply to houses, trams and factories could probably have been exploited at an early stage. Further economies of scope might have been gained later in the century from the supply of electricity along inter-urban routes where electrified railroads were close to roads. Technical developments such as lightweight materials for car bodies, solar-assisted charging, low-drag tyres—particularly after the Second World War—would have helped reduce limitations of range and power for electric vehicles.

Even if technological development had not solved the problem of the low operating range for electric vehicles by 2000, it is reasonable to assume that other means would have been found to overcome technical limitations. For example, commercial street outlets might have developed to enable motorists to exchange batteries in a quick operation akin to filling a vehicle with petrol. Given such options, it is even reasonable to assume that urban densities may not have differed significantly from those of today. To the extent that the rest of the world would also have been using electric vehicles, demand for Australian coal and materials such as aluminium can be assumed to have maintained GDP at historical levels.

It has therefore been assumed in this paper that electric vehicles would have eventually dominated steam in a two-way contest and would have grown in number in an almost identical manner to motor cars during the twentieth century. It is acknowledged that uncertainty in invention and innovation makes other outcomes (path-dependencies) equally possible. The assumption of eventual domination by electric vehicles is a working hypothesis made purely for the purpose of the thought experiment essayed here.

The intensity of competition at the turn of the century to develop a flying machine suggests that air travel may not have been significantly different today even in the absence of the internal combustion engine. Steam-powered propeller-driven flight was demonstrated to varying degrees from the 1870s onwards; with Ader achieving the first take-off under an aircraft's own power in 1890, using steam (Angelucci 1984, p. 40). More importantly, modern aircraft are mainly propelled by jet turbines, which are likely to have been developed at the same time (or even earlier) even without internal combustion engines. (Aviation gasoline, used in piston-driven aircraft engines, accounts for only about 10 per cent of domestic aviation fuel use in Australia today.)

Ships are still largely driven by steam engines, and some modern Australian coastal vessels are coal-fired. As with air transport, it is unlikely that greenhouse emissions from shipping would have changed significantly in the absence of the internal combustion engine. It is possible, however, that more freight would have been transported by ship than is the case today if shipping had offered cheaper freight rates.

In estimating emissions from electric vehicles, one approach would have been to compare fuel intensities from modern vehicles such as the General Motors *Impact* with those from the petrol-powered *Ultralite*. However actual transport emissions are based on average fleet fuel efficiencies which are far higher than those of the *Ultralite*. The more realistic approach adopted has been to assume that the level of primary energy usage and the level of technology available for electricity generation would not have differed substantially from today's levels. On this basis, the main difference between the internal combustion engine and electric vehicles lies in the lower level of non-carbon dioxide greenhouse gases emitted during electricity generation.

Table 3 summarises the likely differences in greenhouse emissions if electric vehicles only had been used in the road and rail sectors. Overall, emissions would have been about 10 per cent lower in 2000 than those currently projected for a transport sector that relies on the internal combustion engine. Table 3 also compares emissions from air transport with those from an alternative like a Very Fast Train. Had this alternative been assumed, total greenhouse emissions from transport would have been about 13 per cent lower than those currently projected. Nuclear power has not been considered here because its effect in terms of reducing greenhouse emissions is obvious, and because it is not clear whether it possessed sufficient cost advantages in a low-population Australia in the 1950s and 1960s to have been introduced on a strictly commercial basis.

TABLE 3 ELECTRIC-EQUIVALENT TRANSPORT SYSTEM IN 2000

(Gg of CO_2 equivalent emissions)

Mode	*Current projections*[a]	*Electric vehicles*[b]	*savings*	*%*
road passenger	44 810	40 329	4 481	10
road freight	27 493	24 469	3 024	11
bus	1 564	1 408	156	10
urban rail	1 107	1 050	57	5
non-urban rail	3 314	3 120	194	6
Very Fast Train[c]	[5 990]	2 261	3 116	60

Notes and Sources

a. BTCE (1995), tables VIII.3, VIII.7, IX.4 and X.5. Current projections figure for Very Fast Train (VFT) refers to domestic air transport. Gg = 10^9 grams.

b. An equal consumption of primary energy was assumed by gasoline-driven and electric road vehicles. Table 3.6 of BTCE (1995) indicates that non-CO_2 emissions form about 3 per cent of electric rail emissions; while tables VIII.3 and VIII.7 show the ratio to be about 14 (cars) and 13 (trucks) in 2000. Savings due to a switch from petroleum to electricity have therefore been estimated to yield emission reductions of about 10 per cent in CO_2 equivalents. A similar method was used to estimate savings resulting from a switch to electric rail.

c. Savings resulting from a switch from air travel to Very Fast Train (VFT) calculated from SSCTCI (1991), table on p. 103, as ratio of primary energy consumption per passenger-kilometre by air (0.85) and VFT (0.27). Because the VFT would use coal-fuelled electricity, the emission level has been adjusted upward by a factor of 90/68 to reflect the different carbon content of avtur and avgas compared with coal (BTCE, 1995, table V.4). The SSCTCI (1991) energy consumption ratios are based on half the electric power for the VFT being drawn from brown coal power stations in Victoria and half from black coal in New South Wales.

CHAPTER 5 CONCLUSIONS

A lot of attention has been given during the twentieth century to the negative aspects of motor car usage. While the negative externalities generated by the motor vehicle are significant, it is also true that non-motorised transport systems created similar externalities even thousands of years before the advent of the internal combustion engine.

The real question that needs to be asked therefore is whether the car is better or worse than the alternatives. Given the debate in recent years on global warming, this paper focuses on greenhouse emissions from the transport sector.

One approach to answering the question of the car's contribution to global warming is a long-term historical perspective that compares transport systems with and without the motor vehicle. Because there are no publicly available historical estimates of greenhouse emissions from the Australian transport sector, estimates have been made for the first time in this paper. They are presented in the appendixes.

There will have been a tenfold increase in greenhouse emissions from the transport sector between 1900 and 2000. Over the same period, population will have increased fivefold, and real GDP 23 times, while urban densities are now only about one third of those in 1900.

Within the limits of long-term historical comparisons and availability of data, it may be concluded that use of the internal combustion engine itself has not contributed disproportionately to greenhouse emissions in the transport sector. The equally qualified corollary is that an economy of size similar to that of today would not have generated a significantly lower quantity of greenhouse gases had the motor car not replaced animals and steam from 1900.

However, if electric vehicles rather than gasoline-powered ones had come to dominate the transport sector early in the twentieth century, greenhouse emissions in the year 2000 would be about 10 per cent lower than current projections.

On this basis, it may be concluded with some strong qualifications that, despite the motor vehicle's dominance as an emitter of greenhouse gases in the transport sector, its development and diffusion have not been entirely negative. However, the situation would have been even better had electric vehicles achieved dominance instead.

APPENDIX I: RIVERBOATS

Riverboats on the Murray–Darling river systems (including the Murrumbidgee and its tributaries) were powered by steam engines. In contrast to seagoing coastal steamships, which used coal, the riverboats used wood for fuel until at least 1900. Coal could not be transported easily to the river ports from coastal coal fields such as those in the Hunter Valley in NSW until railway connections were completed to river towns such as Bourke, and would have been commensurately more expensive.

Wood supplies, on the other hand, were relatively plentiful along the rivers until late into the nineteenth century. Boats purchased wood from woodyards and farmers along the river, or else crews cut their own supplies along the river banks. However, there do not appear to be any published estimates of the amount of wood used by the riverboats of the Murray–Darling system.

Most published work on the riverboats of the Murray–Darling system focuses on describing the 'life and times' associated with the boats and the men who operated them. Even where extracts from logbooks are reproduced in such references, it is apparent that records of fuel consumption were a low priority for riverboat captains, compared with information on the state of the river or progress with the woolclip on the western sheep stations.

NUMBER OF RIVERBOATS

While admittedly incomplete in terms of information, Parsons (1987) provides names of ships, dates of construction and decommissioning, size of hull, and nominal horsepower of engines of all known riverboats from the mid-nineteenth century. Based on this apparently well-researched source, it is estimated that the number of riverboats (excluding barges, sail ships, etc) in 1900 was about 118.

A figure of 118 riverboats probably underestimates the total number of Australian riverine steamers. Phillips (1983, p. 14) states that there were more than 100 steamers on the Murray–Darling system in the mid-1870s, but that there were many smaller, unregistered craft. Most of the boats listed by Parsons

(1987) are registered vessels, because registration records (as well as state Customs data prior to Federation) were a major source of information.

Steamboats used elsewhere than the Murray–Darling have not been included in the estimate of 118 mainly because of lack of specific information about them. Parsons (1987), for example, records the transfer from the 1860s onwards of several Murray–Darling boats (eg two boats called *Murray* but with different registration numbers, the *Burrabogie*, the *Hebe*, and the *Napier*) to Melbourne, Sydney, the Clarence River, and the Gippsland Lakes. It is not clear whether they remained in these areas until 1900. According to (possibly inconsistent) information provided in Purtell (1982), there were probably two passenger and two freight steamers plying the Hawkesbury in 1900. However, no further information is provided about them; and there may have been other ships on the tributaries of the Hawkesbury system.

AVERAGE CONSUMPTION OF WOOD BY RIVERBOATS

It is equally difficult to estimate average or typical consumption of wood by the Murray–Darling riverboats. Boats differed markedly in size, in engine power, in the number and weight of barges towed, and in operating areas (eg lower and upper Murray). In contrast to the sternwheeled Mississippi riverboats, those on the Murray–Darling were mainly sidewheelers. (Longer boats found it difficult to negotiate the sharp river bends.) But some Australian boats (including the *Corowa*) were sternwheelers.

Even for a particular ship, daily wood consumption could vary markedly according to whether it was working with or against the current, the strength of the current, the need to use the engine to winch the ship over sandbars or reefs during periods of low water, time idle in repairs, maintenance or loading, etc. The state of the rivers is virtually an unknown, given the vast area covered by the river system. The Murray could have been low, while the Darling was high because of rainfall in Queensland, or the reverse. Depending on where rain was falling, a river could have been rising and falling in different spots and at different rates. Actual consumption of wood would also have varied according to the species of trees available along different parts of the river, how dry the wood was, etc.

In a personal communication on 14 November 1994, Mr Kevin Hutchinson of the Echuca Port Authority (who has been involved with the restoration and operation of riverboats for many years) estimated that riverboats used about half a ton of wood per hour. However, there is no readily available source of information on the average annual or daily number of hours worked by riverboats, so that the hourly consumption of wood cannot be calculated.

In the absence of any other known information, estimates of wood usage by riverboats were based on the experience of the *Corowa*. Wood taken on by the steamer *Corowa* was estimated from the captain's logbook (Randell ?1993). No 'typical' year or month for the *Corowa* could be identified with any accuracy. The published logbook begins and ends inexplicably in the middle of voyages; and sometimes several months are missing. In the absence of the captain, William Randell, the logbook was (sometimes) kept by others; and the change in priorities in recording information is very noticeable. In Randell's absence there are often periods of days at a time where there is no record of whether wood was taken on.

While Randell himself records quantities and prices of wood purchased (presumably because of his need as owner of the ship to keep accounts), he does not normally specify the quantity of wood taken on when it was cut by the *Corowa*'s crew. Logbook entries generally record no more than 'Stopped to cut wood'. Nevertheless, an entry for 30 August 1882 records 'Stopped to cut wood — cut about 4 tons'. From the logbook it is clear that the time taken to cut and load the 4 tons of wood was just under 2 hours: a rate of 2 tons per hour. Because the logbook invariably records how long the *Corowa* stopped to cut wood, the rate of two tons per hour was used to estimate wood taken on by the ship. For some areas this is likely to be an overestimate because wood may have been less abundant (the township of Bourke, for example, began to experience shortages of wood in the late 1890s), but it has been assumed that the captain would not have stopped to cut wood unless it had been reasonably abundant, because intense competition for cargoes and limited sailing seasons meant that time spent cutting wood imposed an opportunity cost in revenue forgone.

Choice of a representative month or year is precluded mainly by incomplete recording in the logbook even for years which are not known drought years. Analysis of the months for which the logbook has been kept provides no confidently discernible patterns. By default, the year 1882 (for which the logbook appears to be the most complete, and for most of which Captain Randell was the recorder) was chosen. Even so, the *Corowa* was tied up between 13 April and 22 August at Mannum while apparently chartered to a 'Capt. King'. (This is curious because 1882 was a year of unusually large wool shipments along the rivers with strong competition for wharf space (Painter 1979, p. 85). The *Corowa* was also stuck in low water on the Darling from 16 September to 23 November. In all, it appears that the *Corowa* spent only a little over 6 months of 1882 working. (On the other hand, the *Corowa* lay idle for substantial periods in other years too, during painting or other maintenance work).

Estimates of the average number of months or days worked per year by riverboats must be as tenuous as estimates of monthly fuel usage. Boats operated on different parts of different rivers; the rivers themselves flowed at varying rates each year; and boats could be stuck on a reef or sandbank for months and sometimes years. Morris (1953, p.57), for example, cites the comments of the Echuca manager of McCulloch's about a religious captain wont to tie up of a Sunday: 'There are only a few months to run (the Darling) out of twelve, and surely time is too precious for delay'. While the Darling was reputed to run fewer months of the year than the Murray or Murrumbidgee, a single 'typical' figure would be misleading.

Discussion on 14 November 1994 with Mr Kevin Hutchinson suggests that a best estimate number of months worked annually by an average riverboat on the Murray–Darling system would be about 6 months. A period of 6 months is very close to the time spent running the rivers by the *Corowa* in 1882, despite the time spent tied up unproductively at Mannum. It has therefore been assumed that the wood taken on by the *Corowa* during 1882 was as good as any other possible estimate of an 'average' annual fuel usage by the 118 riverboats that appear to have been active in the year 1900.

Aggregation of daily entries in the *Corowa*'s logbook shows that about 518.5 tons of wood were used in 1882 (tons per month were January 55.25, February 20, March 180.5, April 77, May to July nil, August 57.25, September 69, October nil, November 51.5, December 8). At a fuel usage rate of half a ton per hour, this represents 1037 hours of operation. Spread over 6 months and on the assumption of a 7-day work week, the *Corowa*'s average daily operations would have been 5 hours and 42 minutes. Allowing for odd days spent loading or unloading, and the fact that riverboats were by law required to tie up during hours of darkness, these figures suggest that the estimate of total wood used by the *Corowa* in 1882 is at least within the bounds of probability.

Steam engines generate power by heating water in a boiler and leading the steam into the cylinder, where its pressure pushes the piston to the end of the cylinder. The expansive force, or pressure, of steam depends upon its temperature. Brake horsepower (the power required to stop a moving vehicle) or indicated horsepower (pressure measured in the cylinder) are typically used to describe the power output of a vehicle. Because they measure power being generated at a specific time or under specific conditions, brake and indicated horsepower are not particularly useful for comparing average energy usage of riverboats, in the absence of standardised test information. Nominal horsepower is based on the dimensions of the cylinder.

It is arguable that horsepower is directly related to the pressure of steam raised and hence the amount of fuel used. Nominal horsepower is thus an approximate indicator of potential fuel usage under some (undefined) set of standard operating conditions. On the other hand, use of nominal horsepower for comparative purposes requires an assumption that the mechanical efficiency of all riverboat engines was the same.

In the absence of better information, the annual amount of wood used by each riverboat has been estimated as the product of wood fuel usage by the *Corowa* in 1882 (C_{1882} = 518.5 tons) and the ratio of each boat's nominal horsepower (h_i)to that of the 50 hp *Corowa* engine (h_c = 50). (For the 11 ships for which information on horsepower is not provided by Parsons (1987), the median value (15 hp) for the other (107) ships was used.) Total wood usage in 1900 (W_{1900}) by the 118 riverboats is estimated using the following formula:

$$W_{1900} = \sum_{i=1}^{118} C_{1882} * \frac{h_i}{h_c} = C_{1882} \sum_{i=1}^{118} \frac{h_i}{h_c} = \frac{518.5}{50} \sum_{i=1}^{118} h_i$$

On this basis the total amount of wood used by the 118 riverboats in 1900 is estimated in table I.1 to have been 23 042 tons.

TOTAL QUANTITY OF WOOD CONSUMED

It is not clear, however, what the figure of 23 042 tons represents.

Parsons (1987) provides an explanation of terms used with respect to riverboats; but provides only information on tonnage (1 ton = 100 cu. ft) for ships, not wood. McGregor (1981, p.56), reproduces the following from an unidentified but apparently contemporary source about the difficult life of a woodcutter on the Murray:

> The woodcutter ... and his *do* work hard ... Below Swan Hill the price of cord wood is 5/- - a measured ton of 80 cubic feet - that is, a stack 4 ft. high, 5 ft. broad and 5 ft. in length.

Because McGregor does not cite the source of the quote, it was not possible to check on the apparently idiosyncratic arithmetic (4 x 5 x 5 = 80). However, if we assume a cuboid stack of x by y perfectly straight logs of uniform radius r and length z, the proportion of solid wood volume to the volume of the stack must be equal to $xy\pi r^2z/4xyr^2z = 0.79$. (Allowing for crooked branches and logs, the suggestion by Dr John Todd — below — to use 0.75 as the proportion of solid wood content to stack volume is probably more realistic.)

According to Mr Kevin Hutchinson of the Echuca Port Authority (which operates the restored paddlewheelers *Adelaide, Alexander Arbuthnot,* and *Pevensey*), on 14 November 1994, wood was sold in stacks of 4 ft x 4 ft x 4 ft (64 cu. ft). On Mr Hutchinson's suggestion, however, Mr Geoff Corry (a second generation woodcutter in the Echuca district) was also consulted. According to Mr Corry (pers. comm. 15 November 1994), a ton has always been a pile 5 ft wide, 10 ft long and 1 ft high (ie 50 cu. ft) 'in my lifetime, and on this part of the river'. On the other hand, Mr Denver Bains (Australian Bureau of Agricultural and Resource Economics, pers. comm. 15 November 1994) has located handwritten notes dating back to the days of the Bureau of Forestry and Timber which suggest that wood (but not sawn timber) was measured in units of 40 cu. ft.

Given the apparent diversity in units, it is perhaps not surprising that Captain Randell of the *Corowa* may himself have been confused, recording the following entry on 10 April 1882:

> stopped at Hack's wood pile - took 5 tons short @ 4/6. Paid for 1/2 ton too much.

For the majority of entries in the *Corowa*'s logbook, only 'tons' are specified. Of approximately 100 'wooding up' entries for the year 1882, only about 10 specify lengths: between 3 ft and 4 ft, or just 'short'. As might be expected, prices per ton varied according to the length of wood (see for example the entry of 16 March 1882 for wooding up near Tilpa with both 4-ft and 5-ft lengths at 7s and 6s per ton respectively). Prices at different locations along the river were likely to vary even for similar lengths of wood, so they cannot be used to estimate the size of wood purchased. However, the logbook does not appear to refer specifically to 5-ft lengths of wood. It has therefore been assumed that reference throughout the logbook to 'tons' is to 5-ft lengths as the standard size for the *Corowa*'s wood box, because shorter lengths appear to have been recorded specifically.

In itself, the assumption of 5-ft lengths as a standard does not provide any certainty regarding the definition of a 'ton' as used by Captain Randell. Nevertheless, it has been assumed that 5-ft lengths would have been stacked in piles of 50 cu. ft, and that a 'ton' is thus equivalent to 50 cu. ft (1.42 m^3). No adjustment has been made to the estimated total wood usage of 518.5 tons (736.27m^3) in 1882 for the *Corowa* because of the uncertainties associated with references to 'short'. However, any tendency towards an overestimate is likely to be compensated by lack of entries, particularly towards the end of 1882 when wood purchases and wood cutting by the crew appear to have diminished inexplicably.

On the basis of this admittedly very rough computation, it is estimated that riverboats in the year 1900 used 32 700 m^3 of stacked wood.

GREENHOUSE EMISSIONS FROM FIREWOOD COMBUSTION

Dr John Todd of the Centre for Environmental Studies at the University of Tasmania (pers. comm. 22 December 1994) considers that 'the conversion from stacked wood to solid wood and then to weight of wood is very approximate. The conversion from stack volume to solid wood volume depends on how carefully the wood is stacked, the straightness of the wood and the size of wood pieces. For split hardwood, I would assume 75 per cent solid wood in a stack. If limbwood is used the figure would probably drop to around 65 per cent because of bends in the wood causing bigger voids in the stack. I suggest you use the 75 per cent figure. To convert to weight, it is necessary to assume an average density. My guess would be around 900 kg per cubic metre.'

Using the Todd conversion factor, the 32 700 m^3 of stacked wood used by riverboats in 1900 would be equivalent to about 24 525 m^3 of solid wood, or about 22 073 tonnes of wood. Even when wood is air dried (according to Mr Jeff Corry, 15 November 1994, Australian riverboats, unlike their Mississippi counterparts on TV shows, did not emit smoke because only dry wood was used), it would still contain a 'typical moisture content of 16 per cent' (Todd, pers. comm. 22 December 1994). With zero moisture content (oven dry) the wood used would have weighed about 18 541 tonnes. Todd (1993, p. 2) uses an average energy content factor for eucalypt of 19.5 MJ/kg. Applied to riverboats in 1900, this represents 361 550 GJ (0.36155 PJ) of wood consumed.

The NGGIC (1994c, p. 13) algorithm for calculating carbon dioxide (CO_2) emissions from wood combustion is the product of fuel combusted (in PJ), an emission factor for wood (94 Gg CO_2/PJ), and the percentage of wood that is oxidised. Todd (1994, personal communication) considers that an appropriate oxidation factor would be 95 per cent for riverboats.

It is not clear that the NGGIC (1994c) emission factor of 94 Gg CO_2/PJ for wood is entirely appropriate. This emission factor is apparently based on Todd (1993), who himself points out, however, that if firewood usage involves replanting of trees, then the net CO_2 emissions will be dependent only on energy used to harvest and transport the wood. Energy used for the harvesting and transport of wood to the banks of rivers is already taken into account conceptually in appendix II in terms of aggregate animal power used in Australia.

Some of the wood used by the Murray–Darling riverboats would have been replaced by natural regrowth (especially in the forests along the river banks), but much of the land where the wood was cut would have been used for or converted to pasture or crop land by farmers and graziers. Because of the high value of wool and wheat at the turn of the century it has been assumed in this paper that only 25 per cent of the wood used by riverboats involved regrowth, and hence there would have been zero long-term emissions of $C0_2$.

The net effect of loss of a CO_2 sink where land is cleared and regrowth is not permitted depends on whether the land is used for pasture or for sown crops. The issue was not addressed, because use of cleared land for either purpose would involve attribution under NGGIC (1994c) of the lost sink to agriculture, rather than to the transport sector.

Under NGGIC (1994c) guidelines, the riverboat fuel wood taken from land subsequently used for agricultural or pastoral purposes should be attributed to the agricultural sector, rather than to transport. Because the focus of this paper is on comparing emissions in 1900 and 2000, however, it would have been misleading to attribute fuel burnt by riverboats to another sector. Moreover, the wood was actually burnt to generate power, rather than being left to rot in situ or burnt as part of a land-clearing process. Seventy-five per cent of all wood burnt by riverboats in 1900 was therefore considered to have been converted to greenhouse gases.

On this basis, riverboats are estimated to have generated about 24.2 Gg (24 215 Mg) of CO_2 in the year 1900. Using NGGIC (1994c, table 3, p. 12) factors for commercial wood-fired boilers, riverboats are also estimated to have emitted 68.5 Mg of carbon monoxide (CO), 5.2 Mg of methane (CH_4), 1.112 Mg of nitrous oxide (N_2O), and 11.4 Mg of nitrogen oxides (NO_x).

TABLE I.1 FIREWOOD CONSUMED BY RIVERBOATS ON THE MURRAY–DARLING RIVER SYSTEM IN 1900

Riverboat	*nom. hp*[f]	*Corowa hp*	*adj. hp*[d]	*Corowa wood*[e]	*Wood per yr*
Adelaide	36	50	0.72	518.5	373.32
Advance	10	50	0.20	518.5	103.70
Agnes	18	50	0.36	518.5	186.66
Alert	20	50	0.40	518.5	207.40
Alexandra	39	50	0.78	518.5	404.43
Alfred	14	50	0.28	518.5	145.18
Alpha	7	50	0.14	518.5	72.59
Amphibious	16	50	0.32	518.5	165.92
Ariel	14	50	0.28	518.5	145.18
Australien	16	50	0.32	518.5	165.92
Avoca	30	50	0.6	518.5	311.10
Barwon	10	50	0.2	518.5	103.70
Bogan	15	50	0.3	518.5	155.55
Blanche	20	50	0.4	518.5	207.4
Brewarrina	10	50	0.2	518.5	103.70
Cadell	45	50	0.9	518.5	466.65
Cato	15	50	0.3	518.5	155.55
Charlotte[b]	15	50	0.3	518.5	155.55
City of Oxford	5	50	0.1	518.5	51.85
Clyde	10	50	0.2	518.5	103.70
Colonel	12	50	0.24	518.5	124.44
Corowa	50	50	1.00	518.5	518.5
Daisy	5	50	0.1	518.5	51.85
Decoy	40	50	0.8	518.5	414.80
Dispatch	40	50	0.8	518.5	414.80
Dora	2	50	0.04	518.5	20.74
Edwards	12	50	0.24	518.5	124.44
Elizabeth	35	50	0.7	518.5	362.95
Ellen[b]	15	50	0.3	518.5	155.55
Emma	25	50	0.5	518.5	259.25
Emu	3	50	0.06	518.5	31.11
Endeavour	6	50	0.12	518.5	62.22
Enterprise	12	50	0.24	518.5	124.44
Ethel Jackson	62	50	1.24	518.5	642.94
Eva	16	50	0.32	518.5	165.92
Eva Millicent	3	50	0.06	518.5	31.11
Excelsior	28	50	0.56	518.5	290.36
Fairy	6	50	0.12	518.5	62.22
Falcon[b]	15	50	0.3	518.5	155.55
Florence Annie[b]	15	50	0.3	518.5	155.55
Gem	40	50	0.8	518.5	414.8
Glimpse	8	50	0.16	518.5	82.96
Golconda	14	50	0.28	518.5	145.18
Goldsborough	16	50	0.32	518.5	165.92
Goolwa	16	50	0.32	518.5	165.92
Goonda[b]	15	50	0.3	518.5	155.55

TABLE I.1 FIREWOOD CONSUMED BY RIVERBOATS ON THE MURRAY–DARLING RIVER SYSTEM IN 1900 CONTINUED

Riverboat	*nom. hp*[f]	*Corowa hp*	*adj. hp*[d]	*Corowa wood*[e]	*Wood per yr*
Hero	28	50	0.56	518.5	290.36
Industry	15	50	0.3	518.5	155.55
Invincible	25	50	0.5	518.5	259.25
Jandra	10	50	0.2	518.5	103.70
J.H.P.	20	50	0.4	518.5	207.40
Jolly Miller	16	50	0.32	518.5	165.92
Julia	25	50	0.5	518.5	259.25
Jupiter	30	50	0.6	518.5	311.10
Lady Darling	2.5	50	0.05	518.5	25.925
Kennedy	35	50	0.7	518.5	362.95
Lady of the Lake	6	50	0.12	518.5	62.22
Lancashire Lass	16	50	0.32	518.5	165.92
Little Wonder	12	50	0.24	518.5	124.44
Maggie[b]	15	50	0.3	518.5	155.55
Maranoa	30	50	0.6	518.5	311.1
Marion	20	50	0.4	518.5	207.4
Mary Ann	4	50	0.08	518.5	41.48
Maude	10	50	0.2	518.5	103.7
Mayflower	3.5	50	0.07	518.5	36.295
Melbourne[b]	15	50	0.3	518.5	155.55
Menindie	30	50	0.6	518.5	311.1
Milang[a]	9	50	0.18	518.5	93.33
Moira	15	50	0.3	518.5	155.55
Monada	20	50	0.4	518.5	207.4
Mundoo	8	50	0.16	518.5	82.96
Murray ON64221	50	50	1	518.5	518.5
Murrumbidgee	14	50	0.28	518.5	145.18
Murrundi	30	50	0.6	518.5	311.1
Mystery	6	50	0.12	518.5	62.22
Nellie[a]	25	50	0.5	518.5	259.25
Nile	8	50	0.16	518.5	82.96
Nil Desperandum	30	50	0.6	518.5	311.1
Pearl	36	50	0.72	518.5	373.32
Pilot	15	50	0.3	518.5	155.55
Pioneer	10	50	0.2	518.5	103.7
Pride of the Murray	22	50	0.44	518.5	228.14
Prince Alfred	10	50	0.2	518.5	103.7
Princess	53	50	1.06	518.5	549.61
Princess Royal	14	50	0.28	518.5	145.18
Pyap	10	50	0.2	518.5	103.7
Queen	16	50	0.32	518.5	165.92
Resolute	33	50	0.66	518.5	342.21
Rob Roy	25	50	0.5	518.5	259.25
Roma	16	50	0.32	518.5	165.92
Rothbury	30	50	0.6	518.5	311.1
Ruby ON74898	18	50	0.36	518.5	186.66

TABLE I.1 FIREWOOD CONSUMED BY RIVERBOATS ON THE MURRAY–DARLING RIVER SYSTEM IN 1900 CONTINUED

Riverboat	*nom. hp*[f]	*Corowa hp*	*adj. hp*[d]	*Corowa wood*[e]	*Wood per yr*
Ruby ON106118	4	50	0.08	518.5	41.48
Saddler[b]	15	50	0.3	518.5	155.55
Sawmiller	10	50	0.2	518.5	103.7
Shannon	32	50	0.64	518.5	331.84
Struggler	12	50	0.24	518.5	124.44
Success	25	50	0.5	518.5	259.25
Sunbeam[b]	15	50	0.3	518.5	155.55
Tarella	30	50	0.6	518.5	311.1
Teviot	12	50	0.24	518.5	124.44
The Duke of Edinburgh	14	50	0.28	518.5	145.18
Tolarno	18	50	0.36	518.5	186.66
Trafalgar	13	50	0.26	518.5	134.81
Tyro	30	50	0.6	518.5	311.1
Undaunted	11	50	0.22	518.5	114.07
Ventura	10	50	0.2	518.5	103.7
Victor	16	50	0.32	518.5	165.92
Victoria ON48425	40	50	0.8	518.5	414.8
Victoria ON89410	6	50	0.12	518.5	62.22
Wagga Wagga[b]	15	50	0.3	518.5	155.55
Wandering Jew	10	50	0.2	518.5	103.7
Wanera	7	50	0.14	518.5	72.59
Waradgery	50	50	1	518.5	518.5
Wardell[b]	15	50	0.3	518.5	155.55
Wave	6	50	0.12	518.5	62.22
Wilcannia	25	50	0.5	518.5	259.25
William Davies	14	50	0.28	518.5	145.18
				tot. tons[c]	23042.14

a. Parsons (1987) provides only an indicated horsepower (ihp) figure of 50 for the *Milang*. The nominal figure of about 9 hp has been estimated using the relationship between ihp and hp from information given by Parsons for the *Nellie* (ihp = 140, hp = 25).

b. No horsepower data were available for these 11 ships. The figure used is the median value for the other 107 ships in the table.

c. Refer to text for interpretation of tons.

d. Adjusted horsepower (adj. hp) refers to the ratio of the boat's horsepower to that of the *Corowa* (50 hp).

e. The *Corowa* used 518.5 tons of wood in 1882. The wood used by each riverboat is estimated on the basis of the *Corowa*'s usage, multiplied by its horsepower relative to that of the *Corowa*.

f. Nominal horsepower

Source Estimates based on Parsons (1987).

APPENDIX II ANIMAL POWER

During the early years of settlement, the emphasis was on building up herds rather than using horses or cattle for transport or food.

Although the use of animals increased markedly during the nineteenth century, human energy remained an important part of production and transport. On the Richmond River, 'wives of dairy farmers carried water from the river in buckets suspended from a wooden yoke on their shoulders'; and 'in 1888 barely half the farmers who died in northern Victoria had any kind of harvesting equipment listed in the inventories of their estates' (Davison et al. 1987, pp. 71–72). In the more compact cities of the time, walking was a common mode of personal transport.

By the late 1890s, however, animal numbers had increased substantially, partly as a result of mechanisation in the transport sector on long-haul routes. Railway lines and ports required feeder transport, and railways enabled animal feed to be transported in large quantities to the cities.

BULLOCKS

Kennedy (1986, table 2.6, p. 45) estimates that there were about 7200 working oxen in 1820, partly by assuming that working oxen formed about 10 per cent of total cattle numbers. There do not appear to be any other published statistics for working bullocks for the nineteenth century.

An arbitrary assumption was made that the number of bullocks in 1900 (primarily in remote areas, and in forests) was about the same as in 1820; that is, about 7000.

There is little to justify this assumption on a rigorous basis. However, as population grew and pastoral settlement extended to more remote areas, there would have been a continued use of bullocks even though draught horses replaced them in the more settled areas from the 1860s. Kennedy (1986, p. 198) points out that horses displaced bullocks in short haulage and delivery work in towns, and that railways replaced them in the more developed regions. But bullocks remained the major form of haulage in remote areas to the turn of the century. Bullocks were still being used in western Queensland and in timbered areas in the 1930s.

HORSES

Kennedy (1986) provides estimates of horse numbers by colony annually from 1788 to 1928. Figures for 1850 to 1910 are reproduced in table II.1. Although they are included in the 'total' column, Kennedy's figures for the Northern Territory are not shown separately in table II.1: 1880 (2372), 1890 (11 919), 1900 (12 562), and 1910 (24 509).

TABLE II.1 HORSE NUMBERS IN THE AUSTRALIAN COLONIES

Date	*NSW*	*TAS*	*WA*	*VIC*	*SA*	*QLD*	*Total*
1850	111 458	18 391	2 635	21 219	6 488		160 191
1860	251 497	21 034	9 555	76 536	49 399	23 504	431 525
1870	337 597	22 679	22 174	167 220	83 744	83 358	716 772
1880	395 984	25 267	34 568	275 516	148 219	179 152	1 061 078
1890	444 163	31 165	44 384	436 459	187 686	365 812	1 521 588
1900	481 417	31 607	68 253	392 237	166 790	456 788	1 609 654
1910	650 636	41 388	134 114	472 080	249 326	593 813	2 165 866

Source Kennedy (1986, appendix H, pp. 156–161).

More detailed information on numbers of horses in rural and urban areas, or the purposes for which they were used, does not appear to be readily available.

Information is available for New South Wales by type of horse (draught, harness and saddle). Table II.2 shows that almost half the horses in NSW in 1898 were saddle horses, about a third draught, and 26 per cent harness. The *Official Year Book of New South Wales 1904–5*, (1906, p. 273), records that the non-classification of 82 747 horses for 1904 was due to the non-receipt by the Stock Department of returns. Because of the uncertainty associated with the non-returns in 1904, the mix in 1898 was taken as representative of the year 1900. The mix of horse types in NSW from 1886 to 1898 was fairly stable (table II.2), so that this assumption is unlikely to result in significant error.

However, the mix of horse types would have differed by colony. According to Davison et al. (1987, unsourced endnote 80, p. 442) South Australia, where agriculture was more important, draught horses were 66 per cent of the recorded horse population in 1888. Because figures for 1900 are not available, it has been necessary to assume that the NSW data can be applied to the whole of Australia. Although unsatisfactory, this approach is not entirely problematic—Victoria would probably have had a mix of horses comparable to that of NSW;

TABLE II.2 PERCENTAGE OF DRAUGHT, HARNESS AND SADDLE HORSES IN NEW SOUTH WALES

Date	Draught	Harness[a]	Saddle	Non-class	Total stock
1886	29	28	43	-	361 663
1891	31	26	43	-	459 755
1894	31	27	42	-	518 181
1898	31	26	43	-	491 553
1904	27	23	33	17	482 663
1909	30	23	32	15	604 784
1913	35	20	27	18	746 170
1916	40	21	27	12	689 542
1920	39	na	20	na	663 174

a. The *Official Year Book of New South Wales 1904–5*, p. 273, specifies the 'harness' category more precisely as 'light harness'.

Source Kennedy (1986, table 7.2, p. 294), who cites T.A. Coghlan, *The Wealth and Progress of New South Wales 1886–7 to 1900–1*; and the *Official Year Book of New South Wales 1904–5 to 1920–21*.

and the two colonies together accounted for over half of the Australian horse stock in 1900.

If the proportions in table II.2 are applied to Australia as a whole, the total number of **saddle-horses** in Australia in the year 1900 was probably in theorder of 692 150. Most of these would have been used for personal transport (or possibly as packhorses), but some are likely to have been racehorses, thoroughbreds for breeding, or horses bred specifically for export rather than for transport purposes in Australia. (The fact that the saddle-horse category shows the largest drop in the 1904 NSW statistics in table II.2 lends some credence to this view if it is assumed that non-returns were partially due to classifying horses into only three exhaustive categories.)

In 1900, NSW exported 11 594 horses to other Australian states and to New Zealand. But the *Official Year Book of New South Wales 1904–5*, p. 274, states that 'little notice should, however, be paid to the exports to other States of the Commonwealth and New Zealand, as the great majority of the animals are racehorses journeying to fulfil engagements therein, or returning from similar visits to New South Wales'. The total Australian stock of racehorses in 1900 cannot be determined from NSW exports. However, if it is assumed that a specific horse would not have crossed state boundaries more than once a year (reasonably realistic given the rudimentary nature of interstate links), the figure of 11 594 provides a rough lower bound estimate. Taking into account other uncertainties such as the seemingly high number of racehorses, lack of information on breeding horses, and the probability that racehorses would have been maintained primarily in the more urbanised states of New South Wales and Victoria, an arbitrary 10 per cent was added to the New South Wales 'export' figure to give an estimate of about 12 800 saddle horses used for non-transport purposes in Australia in 1900.

Australian horses were also exported to India (for British Army use), Hong Kong, China, Singapore and other destinations at the time of Federation.

During the period 1899 to 1902 NSW exported about 181 321 horses to South Africa. In 1901, a total of 24 993 horses were exported from the Commonwealth as a whole to Natal and Cape Colony, of which 6300 were from New South Wales (*Official Year Book of the Commonwealth of Australia 1901–1907*, p. 282; and *Official Year Book of New South Wales 1904–5*, p. 274). Although many of these would have been Waler saddle horses for military use in the Boer War, some would also have been draught horses for pulling stores wagons and artillery pieces. In terms of total exports, however, the Boer War was a short-term aberration, and probably involved the export of horses that would otherwise have been used domestically for transport. The underlying 'trend' value of annual Australian exports in 1900 was closer to 12 000, of which almost half would have gone to India for military use.

It has been assumed that half of total Australian exports to countries other than South Africa in 1900 would have been saddle-horses (6000), with the remainder split evenly between light-harness (3000) and draught (3000). Taking into account exports of horses and the existence of non-transport animals such as racehorses, the number of saddle-horses available for transport purposes in Australia in 1900 is therefore estimated to have been 673 350.

Applying the 1898 NSW mix of horse types to the total Australian horse population in 1900 gives a gross estimate of **light-harness horses** of 418 510. Allowing for the assumption of exports of 3000, it is estimated that about 415 500 light-harness horses were available in Australia for transport purposes in the year 1900.

An analogous calculation leads to an estimate of 495 993 **draught horses** being available for transport in Australia in 1900. But some of these would have been used full- or part-time for farm work such as ploughing or pulling threshing machines. It has been assumed entirely arbitrarily that half (247 996) were effectively (full- or part-time) devoted to freight transport purposes, with the remainder used for farm work, and mining. Of those used purely for farm work, a proportion would have been used to produce feed for 'transport' horses. This proportion is estimated to have been 25 per cent, equal to the share of oats and hay in the total Australian acreage of crops in 1901–2 (acreages reported in *Official Year Book of the Commonwealth of Australia 1901–1907*, p. 301). On a full fuel cycle basis, therefore, it is estimated that the equivalent of about 309 995 draught horses in Australia were devoted to the transport task.

Drawing together all of the above calculations provides an estimate of 673 350 saddle, 415 500 harness, and 309 995 draught horses available for transport purposes.

Dallas (1968, p. 9) points out that official statistics 'include all horses over a year old whereas few horses under three years were at regular work.' Thompson (1892, p. 615) recommends that Clydesdale 'geldings should not be required to perform heavy work until between 4 and 5 years old .A mare matures a year before the male, and may be put to work somewhat earlier.' Given the cost of purchasing, feeding and maintaining working horses, it is difficult to accept that all owners would have kept a horse for 4 to 5 years before putting it to work. Moreover, Thompson (the Principal of Hawkesbury Agricultural College in NSW) may be promoting an ideal position, and he does refer specifically to 'heavy' work. According to Mr Ken Jacobs, Canberra Veterinary Hospital, the working life for saddle and harness horses was probably 15 to 20 years, and for draught horses about 18 to 20 years.

Unlike motor vehicles, animals consume fuel and generate emissions even when not working. It is arguable that greenhouse emissions from animals that have not yet commenced their working lives should be excluded from total figures. An analogy to motor vehicles might be that the growth stage of a horse is akin to the manufacture of a vehicle. If comparisons between transport modes are made on a full fuel cycle basis (as in this paper) then additional, 'life' or 'systems' cycle emissions should not be included. This would effectively mean reducing horse numbers by about 20 per cent to exclude non-operational horses (it is assumed that old horses were 'scrapped' in various ways, rather than being fed for no gain).

On the other hand, young horses often spent their pre-working lives being trained for later tasks. Seen in this overall perspective, it could be argued that their emissions should be included, just as emissions have been included for working animals even when they are being spelled (usually one day a week). The training period could be seen as making the horse operational ('manufacture' of the horse is then conceptually addressed as the emissions produced by its sires until they reach breeding age) and hence is more like oil in a motor vehicle: by analogy, part of the operational or full fuel cycle approaches only.

There is merit in both approaches. However, it was recognised that a perfect analogy cannot be made with motor vehicles and it was decided to include emissions from horses of less than working age for consistency with inclusion of emissions of non-work periods of older, working horses. No adjustments have therefore been made to the numbers of horses estimated above.

DONKEYS AND MULES

Pointing out that cultural attitudes and colonial tastes favoured horses over other animals, Kennedy (1986, appendixes pp. 123–4) states that 'donkeys and mules appear to have played no significant role in pastoral, agricultural and general haulage developments until the 1900s. Their greater use from 1900 until the 1920s was in direct response to the extension of pastoral and mining developments in the more arid regions of Western Australia, South Australia and Queensland. The long drought at the turn of the century and the arid nature of the regions bordering the centre of Australia appear to have stimulated an interest in draught animals which needed less fodder and water than horses and bullocks.... In 1911, 800 mules were reported working in Queensland's arid districts. Hardy and able to work on food derived from scrub and bushes the donkey and mule had their greatest impact as station and road teams in Western Australia.'

According to the *Official Year Book of New South Wales 1914*, p. 612, 'donkeys and mules are not used extensively in New South Wales, the numbers in 1912 and 1913 being 63 donkeys 138 mules, and 80 donkeys 158 mules, respectively'. The *Agricultural and Live Stock Statistics [of South Australia] for the Year Ending March 31st 1901 with Prefatory Report*, p. xxii, records that for the year ending 31 March 1900, there were '414 donkeys, 177 mules ... compared with ... 884 donkeys, 234 mules ... in the previous year'. No figures were found for Western Australia.

Donkey and mule numbers appear to have fluctuated, and may not have been recorded with a great degree of accuracy, given the remoteness of the pastoral areas. Given that there were about 1000 donkeys and mules in South Australia in 1900 (but only half the number the previous year), it has been assumed (conservatively) that the number of donkeys and mules in 1900 for Australia as a whole was 2000.

CAMELS

In 1840, a dromedary was imported via the Canary Islands for use on a South Australian sheep station; and two were imported into Tasmania. Alpacas were imported experimentally in limited numbers in the 1850s until Peru banned their export. A few Bactrian (two-humped) camels were imported sporadically but never seem to have become popular; although a local dromedary-Bactrian cross in the Kalgoorlie area was considered to be one of the best wagon-pulling camels. Sir Thomas Elder imported about 120 dromedaries into South Australia in 1865 and began a breeding program that helped establish the dromedary as the dominant cameloid used in Australia, although much of his initial stock was wiped out by mange (McKnight 1969, pp. 17–25).

Camels were used by the early explorers. Burke and Wills in 1860 were the first to use camels, but also included horses in their ill-fated expedition from Melbourne to the Gulf of Carpentaria. The Warburton expedition from Alice

Springs to the west coast in 1872–73 was the first to rely solely on camels for transport.

Camels were also used to supply large construction projects in isolated areas. They were used on the construction of the Overland Telegraph Line from Adelaide to Darwin from 1870 to 1872; various survey expeditions; the building of the Queensland border fence; the no.1 north-south rabbit-proof fence in Western Australia; and eventually for carrying railway sleepers for the construction of the transcontinental railway from Adelaide to Kalgoorlie. Camels were also used to carry provisions to isolated stations with backhaulage of wool, especially in drought years when horse and bullock teams could not operate. However, their major use was in carting provisions and equipment to mining areas in the centre and west of the country, with backhauls of mineral ores to railheads.

The normal load for a pack camel was considered to be from 400 to 600 pounds (180 to 270 kg), depending on the size and condition of the animal and on the terrain to be traversed. By the 1870s, however, some teamsters were experimenting with wagons and drays. A single camel 'hitched to a wagon could shift half a ton (about 0.5 tonnes) without strain under normal conditions'. (McKnight 1969, pp. 43–45).

Camel numbers are available from a number of official sources that report on livestock, including the Yearbooks of the various colonial, state, and Federal governments. Known data are summarised in table II.3, which is based mainly on the (somewhat incomplete) collation by McKnight (1969) of official statistics.

The data provided in table II.3 are unlikely to be very accurate. The significant oscillations in camel numbers can be explained to some degree by mineral finds such as those that led to the Coolgardie and Kalgoorlie gold rushes, which are responsible for the sharp rise in (imported) numbers in Western Australia between 1893 and 1896; or by occasional fatal outbreaks of camel mange, which could decimate stocks (McKnight 1969, p. 75). The movement of camels between colonies, combined with differences in timing of stock censuses and the remote areas that were covered also helps explain the discrepancies between totals for Australia and the sums of numbers in individual states from about 1910.

The number of camels peaked in the early 1920s, as a result of competition from motor vehicles and the ending of large projects like the transcontinental railway. On the assumption that the camel population followed a logistic pattern of growth, a logistic function (of the standard form $C = S/(1+be^{-at})$, where C is the number of camels; S is the saturation level in the 1920s; b and c are constants; and t is the year) was fitted to data from 1910 to 1924, in an attempt to extrapolate backwards to the year 1900. Unfortunately, the result

TABLE II.3 NUMBER OF DOMESTICATED CAMELS OFFICIALLY REPORTED BY COLONY OR STATE

Year	WA	SA	NT	Qld	NSW	Australia
1890	45					
1891	42					
1892	395					
1893	673					
1894	2 347					
1895	3 456					
1896	3 984					
1897	3 072					
1898	3 197					
1899	2 571					
1900	3 246	856				
1901	2 596	1 047				
1902	1 519					
1903	2 031					
1904	1 953					
1905	2 413					
1906	2 084	2 452				
1907	3 212	2 592				
1908	3 454	2 816				
1909	3 257	2 358		344	1 482	
1910	3 443	2 870		656	1 013	8 426
1911	3 203	2 761		1 023	971	8 403
1912	3 792	3 199		888	1 721	10 045
1913	4 284	3 783		751	1 792	10 822
1914	4 793	3 773		977		11 453
1915	4 938	4 300		855	1 698	12 389
1916	5 265	3 234		829	2 167	11 904
1917	5 808	3 703		874	2 434	12 734
1918	5 772	3 705		660	2 050	12 284
1919	6 137	2 794		379	1 881	10 953
1920	5 995	4 217		740	1 172	12 649
1921	5 856	3 066	494	936	1 273	11 738
1922	6 473	2 852	470	463	1 384	11 079
1923	6 122	3 207	579	399	819	11 107
1924	6 045	4 076	1 000	362	798	11 853
1925	5 594	2 994	452	480	368	9 904

Sources McKnight (1969, pp. 72–3); figures for South Australia for 1900 and 1901 from *Agricultural and Live Stock Statistics [South Australia] for the Year Ending March 31st 1901*, p. xxii.

obtained for 1900 was considerably lower than the known numbers for Western Australia alone, probably as a result of faulty estimation due to an insufficient number of post-1910 observations. The logistic approach was therefore discarded in favour of simple interpolation based on the available data.

It was assumed (notes to table II.3) that camel numbers were greatest in 1900 in Western Australia and South Australia. (Fortuitously, the numbers for these two states are known from official statistics.) McKnight (1969) and other sources confirm that this assumption is not unreasonable. Victoria and Tasmania did not feature as camel areas, and South Australian figures include the Northern Territory until they split in 1908. Between 1909 and 1918 the proportion of camels in NSW and Queensland to those in WA and SA was about 0.32, fluctuating between 0.26 and 0.37. Applying the proportion 0.32 in the year 1900 yields an estimate of 1313 for NSW and Queensland combined.

On this basis it is estimated that the number of camels used for transport purposes in Australia in 1900 was about 5415.

GREENHOUSE EFFECTS

Greenhouse emissions from animals are composed principally of methane (CH_4)and nitrous oxide (N_2O).

NGGIC (1994a, p. 7), points out that 'data on methane emissions from livestock are limited. For many years, data were only available for animals kept in respiration chambers (airtight chambers that allow measurement of material and energy inputs and outputs, including gas exchange). Recently, new methods have allowed direct measurement of methane output from animals in the field. However, to date, there are insufficient data from these field experiments to derive relationships from which broader predictions of methane emissions can be made. Hence, such predictive relationships remain based on the respiration chamber data.' This fact, together with the fact that the respiration chamber data are based on English experiments rather than Australian diets, means that a considerable degree of uncertainty must be attached to the emission factors used.

Methane can originate both from fermentation processes in the digestive tracts of animals (enteric fermentation) and from anaerobic fermentation of faeces where waste is stored in an anaerobic way. Nitrous oxide is emitted from soil processes when faeces and urea are deposited by range-kept animals or by animals in paddocks or yards.

Estimates of methane and nitrous oxide emissions in kilograms/head/year for different animals are presented in table II.4. The methodology is based on NGGIC 1994a and 1994b. Because contemporary Australian animals such as horses are not used for work, NGGIC estimates do not necessarily give an accurate estimate of emissions in 1900. Adjustments and assumptions were therefore required (detailed in footnotes to table II.4), but these are also likely to have introduced a degree of uncertainty and may not always be fully consistent with each other.

Although they do not cite a primary source of information, Davison et al. (1987, p. 80) state that in 1888 'Melbourne and Sydney each stabled about 20 000 horses'; a proportion of about 6 per cent for Victoria and NSW combined. Even where urban horses were not stabled, street droppings were swept and piled up before disposal at tips or on farmland (or urban vegetable gardens), giving rise to faecal methane emissions. Excluding the Northern Territory, the proportion of urbanised to rural population of persons changed from 0.98 in 1881 to 1.29 a decade later, and 1.34 by 1901 (estimated on the basis of Vamplew 1987, p. 41). It has thus been assumed for the purposes of calculating faecal methane that 100 per cent of harness horses, 50 per cent of draught horses and 25 per cent of saddle-horses were *effectively* stabled. This assumption has been made in table II.4, which shows total methane and nitrous oxide emissions from animals used for transport purposes in Australia in 1900.

FEED INTAKE AND ENERGY CONSUMED

Information on the actual feed intake of horses in 1900 is not clear cut.

Kennedy (1986) uses the (apparently Victorian) figures reproduced in table II.5. Thompson (1892, p. 614), the Principal of Hawkesbury Agricultural College in NSW, states that 'a draught horse in full work will consume about 35 lb. of chaff per day, 10 lb. of cracked oats or maize, and 5 lb. of bran .' Twenty years later, however, the college's farm foreman reported that 'for a heavy draught in active work the average daily ration consists of about 18 lb. of chaff, 9 lb. of crushed maize, and 3 lb. of bran'; although supplementary feed of 'an average of 10 lb. per horse per night' is given for the cold winter months (NSWDOA 1913, p. 7). It is clear from NSWDOA (1913) that feed volume and type differed significantly in different areas of NSW and at different times of the year; and the Berry Experiment Farm reports (p. 10) that 'when the horses are at rest [ie not in active work], our pastures are as a rule quite sufficient to maintain them in good condition .'

The *Official Year Book of New South Wales 1904–5*, p. 273, states that 'New South Wales is specially suitable for the breeding of saddle and light-harness horses ... Fed only on the ordinary herbage of the country, these animals are constantly required to perform long journeys across difficult country.' Kennedy (1986, p. 189) considers that 'grass feeding horses was the general pattern in all the Australian colonies but it imposed serious limitations on the amount of work done in a day and the number of days worked without spelling the horse'. On the other hand, contemporary feeding schedules such as that in table II.5 suggest that grass was by no means the only food source. Owners would have presumably tried to recoup the capital and operating costs of horse ownership through maximum output, while keeping costs down during slack periods. It is likely that saddle-horses were mainly grass fed and draught horses received oats and hay, with harness horses somewhere in between.

TABLE II.4 ANNUAL GREENHOUSE GAS EMISSIONS PER HEAD AND TOTAL FOR ANIMALS

Animal	*Number*	*Enteric CH_4 CH_4/hd/yr kg*	*Faecal CH_4*[a] *stabled animals*[c] *CH_4/hd/yr kg*	*Faecal N_2O*[b] *(range-kept) N_2O/hd/yr g*	*Total CH_4 Mg/yr*	*Total N_2O Mg/yr*
Horse						
draught	309 995	61[d]	6	725.2	19 840	112
harness	415 500	47[d]	6	554.6	22 022	0
saddle	673 350	36[d]	6	426.6	25 251	215
camel	5415	90[d]	0	426.6	487	2
donkey/ mule	2 000	20[d]	0	142.2	40	0.3
bullock	7 000	63[e]	0	426.6	441	3

a. NGGIC (1994a, p. 36) recommends a zero factor for methane emissions from manure for all range-kept livestock because 'in the absence of concentrated sites for waste deposits or treatment of wastes, the Working Group believed that anaerobic conditions, a prerequisite for methane production, were unlikely to exist'. This approach was accepted for camels, donkeys, mules, and bullocks. In the year 1900, however, some horses would have been stabled, with stalls being mucked out regularly and waste stored. Urban street manure was also piled up before being dumped or transported to rural fields or urban vegetable patches as fertiliser. In the absence of data, it was assumed that a dairy cow (in milk or dry) in contemporary Australia could be taken as a rough approximation of an average working horse kept in a stable. Using the factor of 0.016424 kg/head/day given in NGGIC (1994a, p. 31), it was estimated that stable-kept horses would produce 6 kg/head/year of methane from faecal deposits.

b. According to NGGIC (1994a, p. 45), very little is known about the nitrogen intake and nitrogen excretion rates of livestock other than cattle. Default excretion rates are based on cattle and sheep, and are given as 2.72 kg of nitrogen/head/year for donkeys and mules; and 8.16 kg of nitrogen/head/year for horses, bullocks and camels. The figures in the table were calculated using the algorithm on p. 16 of NGGIC (1994b); but scaling factors of 1.7 (draught), 1.3 (harness) and 1.0 (saddle) were applied to horses to reflect differences in the volume of feed intakes and hence excretion. Nitrogen excretion rates for all animals in the table were also multiplied by a factor of 1.85 (see note d) to reflect increased feed intake when animals were used for work. Only non-stabled horses (note c) were considered to produce N_2O emissions.

c. In calculating total methane emissions, it was assumed that about 25 per cent of saddle-horses, 100 per cent of harness horses, and 50 per cent of draught horses were effectively stabled (see text).

d. NGGIC (1994a, p. 27) provides default emission factors for horses as 18 kg of methane per head per year; 45 kg (the figure on p. 28 of the source is given incorrectly as 26 kg; the correct figure is on p. 70) for camels; and 10 kg for donkeys and mules. According to Dr Mark Howden (Bureau of Resource Sciences, Canberra, pers. comm. 15 December 1994), who chaired the Working Group that produced NGGIC (1994a) Workbook 6.0, the original source was not clear on whether the emission factor of 18 kg/head/year was based on a maintenance diet or was for a working horse, but he considered that the laboratory tests used would have involved a diet closer to maintenance. However, Dr Esala Teleni of the Graduate School of Tropical Veterinary Medicine at James Cook University, Townsville, has conducted experiments with working buffalo. According to Dr Teleni (pers. comm. 21 December 1994) working buffalo require between 1.7 and 2.0 times the feed of non-working animals. Woodruff (1912, p. 66) provides calorific equivalents for categories such as 'bus-horse', 'parcel Vanner', etc, but these figures could not be used, because of lack of detail on the composition of the Australian horse population. However, Woodruff also reports (p. 45) experimental data showing that 'five-twelths of a suitable working ration is sufficient for purposes of maintenance', giving a feed multiple of roughly 2.4 for working animals. Each of the enteric methane emission figures for horses, camels, and donkeys/mules was therefore multiplied by 2.0 as an approximate 'working animal' factor, giving 36 kg/head/yr for saddle-horses, 90 kg/head/yr for camels, etc. Table II.5 shows that draught and harness horses ate more than saddle-horses did. The enteric methane emission factors were therefore further scaled up by factors of 1.3 (harness) and 1.7 (draught). No scaling factor was applied to emissions from bullocks, because the estimate for bullocks was based on a steer that was being fed to gain weight, rather than being on a maintenance diet (note e).

e. A bullock was assumed to be equivalent to a steer more than one year old in Queensland, averaged across all four seasons. The emission factor was calculated on the basis of NGGIC (1994a, pp. 9–12). The calculation therefore represents cattle that are gaining weight; but this has been assumed to be roughly equivalent to the energy intake of a working horse that is not gaining weight.

Sources Text and tables in appendix II; NGGIC (1994a,b), various algorithms and sections.

TABLE II.5 AVERAGE DAILY FODDER INTAKE FOR WORKING HORSES

(pounds)[a]

Feed type	Heavy draught	Harness	Saddle
Wheaten or oaten chaff	25	20	15
Oaten or grass hay	10	7	5
Crushed oats	8	5	3
Bran	1 to 2	1	2
Total	45	34	27

a. One pound (lb) is equivalent to 0.454 kg.

Source Kennedy (1986, table 6.0, p.190), who cites *The Weekly Times Farmer's Handbook*, Melbourne, n.d., p. 152.

TABLE II.6 ENERGY CONSUMED[a] BY TRANSPORT ANIMALS IN 1900

Animal	Number[b]	Starch equivalent[c] of daily feed		Energy consumed per year
		(kg)	(MJ)	(GJ)
Saddle-horse	673 350	2.38	37.59	9 237 785
Harness horse	415 500	3.10	48.83	7 405 120
Draught horse	309 995	4.58	72.17	8 165 415
Donkey/mule[d]	2 000			16 060
Camel[d]	5 415			193 815
Bullock[d]	7 000			190 530

Notes and sources

a. It has been assumed that all animals worked, primarily because of the expense of buying, equipping and maintaining them. Even when 'spelled' (eg on Sundays), working animals would have required more than a maintenance level diet to recoup their strength. No distinction has been drawn between fodder-fed and grass-fed animals, on the basis that working animals would have required roughly equal intakes of energy, with grass-fed animals requiring more time to forage than those fed by their operators.

b. Table II.4 above.

c. Woodruff (1912, table III, facing p. 42) gives the starch equivalents for a range of horse fodder, including oats (60.14 per cent), bran (53.76 per cent), oat straw (10.71 per cent), wheat straw (0.96 per cent), hay (an average of about 30 per cent), and pasture grass (10.07 per cent). These percentages have been applied to the weight of fodder eaten daily by each type of horse as shown in table II.5 above, with weights of starch equivalents converted to kilograms. The energy content of the starch equivalent has been converted to mega joules (MJ) on the basis of Woodruff (1912, p. 50), who claims that experimental results show that 1 lb of starch when completely digested produces about 1710 kilocalories. That is, 1 kg of starch consumed by a horse yields about 15.77 MJ of energy, although Woodruff points out that only about 30 per cent is converted to actual work output by the animal.

d. Feed intakes by camels, donkeys and bullocks are unknown. Given that enteric emissions of CH_4 are roughly related to volume of feed consumed, the data in table II.4 were used to adjust intakes. For example, a camel's intake of feed relative to that of a saddle-horse would be proportional to their respective enteric emissions (90/36). On this basis, a camel could be reckoned to have consumed {(90/36)*37.59*5415} = 509 GJ of feed daily. Identical calculations were carried out for camels relative to harness and draught horses, giving a mean daily intake of 531 GJ. An analogous procedure was followed for donkeys/mules. Bullocks were assumed to be identical to draught horses. Daily intakes were converted to annual consumption by multiplication by 365.

Camels, bullocks, donkeys and mules can be assumed to have been mainly grass fed, although bullocks engaged in heavy work would have occasionally required supplementary feed.

Because methane emissions for greenhouse accounting purposes are primarily due to enteric fermentation, the volume of feed rather than its energy content (which would be relevant for carbon dioxide emissions) is the critical factor. Relative volumes of feed intake by different types of horses have already been taken into account in table II.4 in estimating annual greenhouse emissions per animal.

Woodruff (1912, p. 50) gives the heat value of 1 lb of starch fully digested by a horse as 1710 kilocalories (but points out that only about 30 per cent is convertible to actual work by the animal). This is equivalent to 1 kg of starch producing 15.76 MJ of energy. Woodruff (table III, facing p. 42) also provides 'starch equivalents' for a variety of horse fodder. Applying these values to the quantities of fodder in table II.5 yields the estimates in table II.6 of energy consumed by transport animals in about 1900. About 25 208 725 GJ of energy were consumed; about 30 per cent of all energy consumed by the transport sector in 1900.

APPENDIX III RAILWAYS AND TRAMWAYS

Railways were built from the mid-nineteenth century as a form of long-distance transport into the continental interior; and to some extent for public transport within the large cities. Steam and horse trams were also used for public transport in urban areas in the late nineteenth century. Electric-powered urban transport grew quickly only from the beginning of the twentieth century in parallel with street lighting and domestic usage of electricity.

RAILWAYS

The formation in 1848 of the Sydney Railroad and Tramway Company saw the first attempt in Australia to construct a railroad. However, the company's plan to link Sydney, Parramatta and Liverpool was frustrated by the general exodus of labourers from Sydney following the discovery of gold. Despite subsidies in 1852 by the NSW Government to bring in 500 immigrant labourers, a similar fate befell the Hunter River Railway Company, formed in 1853 to construct a line from Maitland to Newcastle. The first operational railway in Australia was completed by the Melbourne and Hobson's Bay Railway Company in 1854 and ran from Flinders Street to Port Melbourne.

By 1901, over 13 550 miles (21 800 kilometres) of government and private rail lines had been opened for traffic within Australia. Approximately 980 miles were private lines laid down primarily for the purpose of hauling timber, coal, and other minerals rather than passengers. Because coastal towns were well served by sail and steam ships, early railway lines radiated from the coast inland. However lines were progressively built (albeit using different gauges) linking colonial capitals. By 1889 railway communication was complete between Brisbane, Sydney, Melbourne and Adelaide; although different gauges meant that transhipment was necessary between state systems. A useful, detailed summary of railway (and tramway) construction and traffic is provided in the *Official Year Book of the Commonwealth of Australia 1901–1907 (no. 1, 1908)*, pp. 551–597.

Information on fuel usage is not readily available. Annual reports on the operations of the state railways often provide expenditure figures but not physical quantities. Tables III.1 and III.2 provide estimates for coal and other fuel used in 1900, but rely on a diversity of sources and different years. Overall, about 681 969 tons of black coal, 89 784 tons of brown coal, 6 tons of charcoal, 775 tons of coke, and at least 9037 tons of wood were used in 1900 by Australian private and government railways. Figures for charcoal, coke and wood are likely to be underestimated, because they could not be obtained specifically for each state.

TRAMWAYS

Tramway systems in metropolitan centres at the turn of the century included horse-drawn vehicles, cable cars (mainly in Melbourne), steam-driven trams and electric trams. The *Official Year Book of the Commonwealth 1901–07* is the main source of information available.

Information on horse-drawn trams was not collected, because greenhouse emissions from horses are already included under total horse numbers. No information appears to be available on Sydney's steam trams, but tram services were provided as part of the state railway system. It has therefore been assumed that the coal used by steam trams in Sydney is already accounted for in table III.1, as part of the rail sector.

No specific information was found on the use of coal in the 11 engine houses used to drive Melbourne's cable trams, which ran a total of almost 9 million miles in 1901. Keating (1971) is a major source on Melbourne's cable cars, but provides relatively little statistical information. Nevertheless, it has been possible to derive an estimate of 61 tonnes for 1900 in table III.4.

The amount of power used by electric trams in each state is available in terms of kilowatt-hours (table III.4), but little is recorded about the thermal efficiency (power output to energy input) for electricity generation in 1900. Existing suppliers such as Pacific Power and the successor agencies to the State Electricity Commission of Victoria either did not exist then, or do not hold records. Neither Pacific Power nor PowerNet Victoria were able to specify historical thermal efficiencies, although PowerNet (Richard Hoy, pers comm 1995) engineers considered that it would have been less than 20 per cent.

It was necessary therefore to rely on Lincolne (?1954, p. 20), who reports for generators operated by the Melbourne City Council that:

> Costs in those days provide interesting reading in 1954. The four twin cylinder compound horizontal Otis engines, rated at 300 B.H.P. at 82 r.p.m. installed in 1894, cost £9921. ... The boilers - by Babcock and Wilcox - were each rated at 7200 lbs. per hour at 150 P.S.I. and were hand fired. If initial cost was low, so also was the efficiency. This was stated as '129 watt-hours per lb. of coal.' To thoroughly appreciate this, one must remember that, in those days, coal was

> really coal. The plant installed in 1900 was even lower in price per installed kW ... The efficiency of these sets was better but by no means high when compared with modern generating costs. An average steam consumption was approximately 35 lbs. of steam per kWh.

As hinted in this passage from Lincolne, black coal was used for electricity generation by the various private companies in Victoria in 1900. It was not until 1918 that the Victorian Government formed a committee to investigate the proposed generation of electricity from local brown coal. Black coal was also used in Adelaide (*Jubilee Souvenir of Public Electricity Supply in South Australia, 1899–1949*, no page number) by the South Australia Electric Light and Motive Power Co. until the development of the Leigh Creek deposits in the 1940s. Power stations in NSW would have relied on black coal; and it is likely that those in Tasmania and Western Australia would have imported black coal from NSW or used local sources, such as Collie coal in Western Australia.

It is important to appreciate also that efficiency figures could have changed rapidly as new engines were installed. On p. 227, for example, Lincolne (?1954) reports of the Electric Light and Traction Co. Ltd (from 1900 the other major supplier in metropolitan Melbourne apart from the Melbourne City Council) that:

> An idea of the improvement in efficiency may be gathered by a glance at the steam consumption figures. This was originally [?1897] 120 lbs. per kWhr. By April 1903 it had been reduced to 80 lbs. and by August it was 55 lbs.

A table presented by Lincolne on p. 71 shows steam consumption of Victorian power stations in lb/kWh at full load down to about 11 by the early 1920s.

In the absence of any other information on average thermal efficiencies, it was assumed that the 1894 figure of 129 watt-hours per lb of coal had improved by 1900 in approximately the same ratio as the machines used by the Electric Light and Traction Co. of 120 lb of steam/kWh to 80 lb/kWh, giving an output of {(120/80)*129} watt-hours per lb of coal. That is, it was assumed that an average generator produced 427 watt-hours per kg of black coal used (427 kWh/tonne).

Professor Geoff Sergeant of the University of Technology in Sydney (pers. comm. 16 January 1995) considers that the *average* net thermal efficiency of coal-fired power plants from about 1900 to 1910 was 4 or 5 per cent, increasing steadily to 20 per cent between 1915 and 1930. (Comparing mechanical and animal thermal efficiencies, Woodruff (1912, p. 50), states that 'in a good type of steam-engine it is not possible to get more than 15 per cent. of the total energy of the steam out in useful work, whereas the body is much more economical, and gives out as work about 30 per cent. of the energy it receives.') A figure of 427 watt-hours per kilogram of coal represents a thermal efficiency of 6.4 per cent (427*3600 = 1.54 MJ of energy produced from 23.9 MJ of coal). It is therefore in roughly the same order of magnitude as the Sergeant estimate.

GREENHOUSE EMISSIONS

Table III.3 summarises the quantity of each fuel used by railways in metric tonnes, energy content and greenhouse gas emissions.

Cable, steam and electric tramways all relied on coal, and horse trams were pulled by methane-emitting horses. From table III.4 it can be seen that coal usage by tramways that is not already accounted for under railways data was about 105.5 tonnes. Direct emissions of methane are accounted for already under animal emissions in appendix II. Assuming similar combustion, energy, and emission factors as for railways (boilers in 1900 were assumed to be more akin to commercial boilers today rather than to modern industrial or electricity generation equipment), Australian tramways in 1900 are estimated to have used about 2521 GJ of coal energy, emitting 0.216 Gg of CO_2, 0.468 Mg of CO, 0.024 Mg of CH_4, 0.567 Mg of NO_x, and 0.142 Mg of N_2O. Fugitive CH_4 emissions from coal seams released during mining have been included as part of coal usage by railways (note h, table III.3).

TABLE III.1 FUEL USED BY GOVERNMENT RAILWAYS, 1900[a]

	Unit	States and Territories						
		NSW	Vic	SA & NT	WA	Qld	Tas	Cwlth
Miles track open	miles	2 846[h]	3 237[h]	1 882[h]	1 355[h]	2 801[h]	438[b]	
Train miles run	miles	10 763 697[h]	11 066 016[h]	4 159 945[g]	4 216 161[d]	5 815 282[h]	895 682[h]	36 916 783
Engine miles run	miles		13 383 130[m]	5 876 817[g]			1 132 135[b]	
Locomotives	no.	495[l]	533[i]	347[g]	229[l]	349[i]	68[b]	
Passenger journeys	no.	29 261 324[h]	54 704 062[h]	7 416 506[g]	6 823 453[h]	3 495 841[e]	683 015[b]	
Passenger miles								
Freight total	tons	6 398 227[h]	3 381 860[h]	1 485 976[g]	1 719 720[h]	1 688 635[e]	308 453[b]	
minerals	tons			793 998[g]		578 755[e]		
agric. produce	tons			126 027[g]		351 026[e]		
wool	tons			19 196[g]		32 472[e]		
timber	tons			-		431 024[e]		
livestock	tons			29 410[g]				
general	tons			517 345[g]		295 358[e]		
Fuel								
black coal	tons	118 698[f]	202 631[n]	90 304[g]	103 747[d]	131 840[e]	14 223[b]	661 443
brown coal	tons		89 784[n]					89 784
charcoal	tons			-			5[b]	5
coke	tons			446[g]			270[b]	716
firewood [q]	tons			4 276[g]		1 000[e]	3 031[b]	8 307

Notes and Sources see table III.3

TABLE III.2 FUEL USED BY PRIVATE RAILWAYS, 1900[a]

		States and Territories						
	Unit	*NSW*	*Vic*	*SA & NT*	*WA*	*Qld*	*Tas*	*Cwlth*
Miles track open	miles	80[h]	0[h]	0[h]	635[h]	103[h]	156[c]	975
Train miles run	miles							867 641[j]
Engine miles run	miles							
Locomotives	no.	19[k]	0[h]	0[h]	10[k]	22[k]	16[c]	
Passenger journeys	no.						67 194[c]	
Passenger miles								
Freight total	tons						194 103[c]	1 482 175[j]
minerals	tons							
agric. produce	tons							
wool	tons							
timber	tons							
livestock	tons							
general	tons							
Fuel								
coal (black)	tons	4 556[p]	0	0	4 530[p]	8 311[p]	3 129[c]	20 526
charcoal	tons		0	0			1[c]	1
coke	tons		0	0			59[c]	59
firewood[q]	tons		0	0		63[p]	667[c]	730

Notes and Sources for tables III.1 and III.2

a. Unless otherwise stated, 12 months to 31 December 1900.

b. *Tasmanian Government Railways Report 1900*, tables 36 (p. 46) and 40 (p. 48). The figure for coke is given as 270 'loads'. A load has been assumed to be 1 ton in weight.

c. *Statistics of the Colony of Tasmania for the Year 1900*, table on p.159; and source b. above. Fuel usage for private railways has been estimated by scaling figures for government railways by relative miles of track open and by relative amount of freight carried to represent work done (energy used). (Engine miles run by private railways are not available.) For example, coal = 14223 x (156/438) x (194103/308453) = 3188 tones. Figures have been rounded to the nearest digit. Coke usage is given as 59 'loads', but a load has been assumed here to be 1 ton in weight.

d. *Report on the Working of the [Western Australian] Government Railways and Tramways for the Year Ended 30 June 1900.* The report covers government tramways as well as railways. Data on p. 13 indicate that extensive use of Collie coal began in about September 1899 as a substitute for Newcastle coal. The average costs per ton of coal in 1899–90 are given as 2.44d. (Newcastle) and 1.66d. (Collie) per train mile.

e. *Report of the Commissioner for [Queensland] Railways for the Year Ended 30 June 1900.* The figure for livestock is given as £167 153 rather than in tons.

f. *Report of the Royal Commission of Inquiry into the [NSW] Railway Administration*, Exhibit Y1 (Return showing quantity of coal supplied annually from each colliery to the Railway Commissioners from 1 July 1893 to 30 June 1905). Because NSW was virtually a self-sufficient producer of coal, and because collieries were connected to railways, reliance on imports by railways would have been negligible. Figures for total imports (all users) of coal into NSW are compatible with this view.

g. *Annual Report of the South Australian Railway Commissioner for the Year 1900–1901*, tables on pp. 6, 46–7. Figures include the Palmerston Line (Northern Territory). The South Australian Railways also operated 16 miles of horse-drawn track. About 7 miles of the 16 appear to be the Goolwa to Port Elliot horse tramway opened in 1854 to connect with the Murray–Darling riverboats (footnote to table on p. 552 of source h. below).

h. *Official Year Book of the Commonwealth of Australia, 1901–1907*, pp. 552–4. Data are for 12 months to 30 June 1901. Under agreements with some private railway operators, state government railways used private as well as publicly owned rail track (footnote to table on p. 554). Not all government and private railways were interoperable even within the one State because of different gauges. In Victoria, South Australia and Tasmania, even the state railway systems themselves operated more than one gauge of track.

i. CBCS (?1910), table 9, p. 12. Numbers refer to 12 months ending 30 June 1901.

j. Train miles run and tonnage carried in 1905 are available from p. 567 of the *Official Year Book of the Commonwealth of Australia 1901–1907.* Data on pp. 552–3 in the same source show that the numbers of miles of private railway track open in Australia for the years to 30 June 1901 and 1905 were 980 and 1067 respectively. Private train miles run in 1900–01 were estimated as the product of 944 666 (private railway train miles run in 1905) and the ratio 980/1067, on the assumption that the profit motive would have resulted in approximately the same proportion of usage to capacity. Tonnage carried by private railways was estimated as the product of 1 613 756 (private railway tonnage carried in 1905) and the ratio of train miles run in 1901 and 1905 (867 641 and 944 666).

k. Figures for NSW and WA are as at 30 June 1906, as shown in the table on p. 581 of source h. The figure of 22 for Queensland is for the year 1908 as given on p. 14 of CBCS (?1910).

m. *Report of the Victorian Railways Commissioner for the Year Ending 30 June 1901.*

n. Taken from appendix B (p. lii) of *Royal Commission on the [Victorian] Coal Industry.* Figures are given for the years 1887–88 to mid-1905, according to Victorian-sourced and NSW coal. For 1900–1, 82 784 tons of Victorian coal was used by locomotives, and 202 631 tons of NSW coal was used. A further 7000 tons of coal (presumably Victorian) was used in calendar year 1901 in workshops, for lighting, etc: appendix GG (p.xxxvii) of *Final Report of the [Victorian] Royal Commission on Management of the Railway Department.*

p. Comparative figures on engine miles run were not available. Estimates were made on the basis of relative numbers of private and government locomotives on the assumption that their respective usages were about the same. For example, NSW private railways are estimated to have used 19/495 times the amount of coal (118 698 tons) used by government railways.

q. Tons in weight have been taken as recorded. Wood taken on by riverboats was also measured in 'tons', but because weighing facilities were not generally available along riverbanks, the unit 'tons' was in fact a volume measure (probably 1.42 m^3). It has been assumed here that tons are a weight measure for railways, because weighing facilities (weighbridges) would have been available.

TABLE III.3 GREENHOUSE GAS EMISSIONS FROM AUSTRALIAN GOVERNMENT AND PRIVATE RAILWAYS, 1900

Fuel	*Tonnes*[a]	*Energy*[b] *(GJ)*	CO_2[c] *(Gg)*	*Co*[c] *(Mg)*	CH_4[c] *(Mg)*	NO_x[c] *(Mg)*	N_2O *(Mg)*
black coal	692 881	16 559 855	1 416	3 075	158 +308[h]	3 722	932
brown coal[d]	91 221	893 966	81	146	8	96	44
charcoal[e]	6.1	105	0.007	0.024	0.002	0.003	0.0003
coke[f]	787	21 249	18	4	0.202	5	1
wood[g,e]	9 182	150 401	10	29	2	5	0.463
Total	..	17 625 576	1 525	3 254	168	3 828	978

Notes and Sources

a. Totals from tables III.1 and III.2

b. Energy content taken from table 10, p. 51 of Bush et al. (1993) as 'unwashed steaming coal' (23.9 GJ/t) for black coal, 9.8 GJ/t for Victorian brown coal, 27.0 GJ/t for coke. An energy content of 19.5 GJ/t was used for oven-dry wood, on the basis of Todd (1993, p. 2). Charcoal was assumed arbitrarily to have a 5 per cent higher energy content (20.5 GJ/t) than wood.

c. NGGIC (1994c) was used to convert fuels into greenhouse gases: table 2 (p. 11) for carbon dioxide, and table 3 (p. 12) for the other gases. An emission factor is not given for coke, so it was assumed to be equal to that for coal. An oxidation factor of 95 per cent rather than 99 per cent was used to estimate CO_2 emissions, in order to reflect less advanced boilers in the year 1900.

d. NGGIC (1994c, table 3, p. 12) does not give non-CO_2 emission factors for brown coal boilers for the category 'Commercial'. Ratios between black and brown coal (tangentially fired) for each gas for the 'Electricity Generation' sector were therefore used to adjust the 'coal-fired boilers' category in 'Commercial'. For example, CO emissions from brown coal are calculated as (11.7/13.3)*(185.71)*(0.893966) Mg.

e. Only 75 per cent of the weight of wood and charcoal was considered to have been converted to CO_2, on the assumption that 25 per cent of the forests cleared in harvesting the wood would have regenerated, an assumption also made in appendix II for wood used by riverboats.

f. NGGIC (1994c, table 3, p. 12) does not give non-CO_2 emission factors for coke, so it was assumed that emissions from coke usage were equivalent to those from commercial coal boilers.

g. Wood used was air-dried. Totals were converted to oven-dried equivalents (air-dried weight multiplied by 0.84 — on the basis of Todd (pers comm 1994) —prior to application of the energy content coefficient in footnote b. The same adjustment was made for charcoal.

h. Estimate of CH_4 emissions released from coal seams during mining, based on NGGIC (1994d, p. 30), assuming all coal sourced from one Class B (non-gassy) underground coal mine. Full fuel cycle estimates of greenhouse emissions would include fugitive CH_4 emissions from coal seams as well as those from combustion of coal. Coal used includes 105.5 tonnes used by tramways (table III.4).

TABLE III.4 POWER AND FUEL USED BY TRAMWAYS[a]

State[b]		*Miles of track open*	*No. of miles run*	*Passengers carried*	*Power (kWh)*	*Coal (tonnes)*
NSW						
Electric	Sydney	45	3 993 407	49 068 661	10 043 544	23.5
	Other[j]	12			2 678 278	6.3
Steam[c]	Sydney	13				
	Other	17				
Horse[d]		1				
Cable[e]		2				
Victoria						
Cable (steam power)	Melb	44	8 964 734	47 195 647		61[k]
Electric[f]	Vic	10	326 878	1 214 323	331 712	0.8
Horse		9				
Queensland						
Electric	Brisbane	21	2 756 443	16 183 801	3 192 955	7.5
Shire tramways[g]		163			1 520 455	3.6
Western Australia						
Electric[h]	WA	17	721 056		806 184	1.9
Horse		23				
Tasmania						
Electric[i]	Hobart	9	321 633	1 734 120	368 747	0.9
Steam	Zeehan	3	7 488	9 970		

a. For year to 30 June 1901 unless otherwise stated.

b. Horse tramways were used in Adelaide up to about 1906. Electrification of lines began about 1908.

c. Broken Hill (6 miles) and Parramatta (5 miles) steam railways opened in 1902. Figures for 'other' refers to Newcastle steam railway in 1906–7. Sydney figure is for 1906–7.

d. 1906–7.

e. Sydney's cable tram is not recorded separately by the source and probably appears as part of the 'steam' category for Sydney. The *New South Wales Statistical Register for 1902*, pp. 998, table 561, shows that almost 2 miles of cable tram still existed on the North Shore as at 30 June 1900, but the line had been entirely converted to electricity by 1903.

f. For year 1903.

g. Motive power not specified. However, table 16, p. 16 of CBCS (?1910) gives total electric tramways for Queensland as 31 at 31 December 1909. Ten miles of shire tramways were assumed to be electric in 1901, with power output at {(10/21) *3 192 955} kWh.

h. Power source not given. Estimate based on properties of tram miles run in 1901 and 1903 (721 056/1 396 888) and power used in 1903 of 1 561 804 kWh.

i. Power used for 1901 estimated as proportion of tram miles run in 1901 to tram miles run in 1904, multiplied by kilowatt-hours used in 1904: {(321 633/330 451)*378 857}.

j. For year 1906–7. Power output apportioned using {(12/45)*10 043 544}.

k. The *Report of the [Victorian] Royal Commission on Tramway Fares Revision*, appendix no. 6, p. lxxvii gives the cost of (non-horse feed) fuel usage for the Melbourne Tramway and Omnibus Co. Ltd. for the years 1899, 1900 and 1901 respectively as £9498, £10 085, £15 947. The corresponding average yearly prices for coal imported from New South Wales were estimated as 164d., 206d., and 219d., based on appendix B, p. lii, of *Royal Commission on the [Victorian] Coal Industry:* imputed wharfage of 1s. (12d.) that the Victorian Railways, as a government department did not pay (p. xliii), has been included in these prices. An average consumption level was taken for the three years 1899 to 1901 (58, 50, and 74 tons respectively) to give an estimate of 61 tonnes because it was not entirely clear if the data on fuel usage was given in financial years, although this could be expected to have been the case.

Source *Official Yearbook of the Commonwealth of Australia 1901–1907*, pp. 588–97.

APPENDIX IV INTERNATIONAL AND COASTAL STEAM SHIPS

Sea transport was an important link between coastal cities and towns in Australia, particularly before the connection of the south-eastern capitals by rail in 1889. Davison et al. (1987, p. 94) point out that:

> If we are to understand transport in the nineteenth century, we must think of the sea not as a border but as a ring road ... Sea transport was very cheap ... People moving goods always sent them to the nearest port. Every inlet that gave some shelter to shipping had been used as a port.

Global development of steam shipping was relatively rapid following improvement by James Watt of the steam engine in 1775. Crankshafts that transformed linear motion to rotary motion were invented in 1801, paddlewheels were replaced from 1804 with propellers driven by coal-fired (rather than wood-fired) boilers, and high pressure, cylindrical boilers from the 1870s were combined later with multiple cylinders to increase the efficiency of steam usage.

A major feature of late nineteenth century shipping was the replacement of sailing ships with steam ships. According to Davison et al. (1987, p. 84):

> From the late 1870s, when the number of steamers entering Australian ports first exceeded the number of sailing vessels, the demand for bunkering coal increased steadily. By 1888, steam was the standard form of maritime transport, not only for passengers and mail but for all except the heaviest and bulkiest cargoes ... Even the smallest ports along the Queensland and northern New South Wales coasts were served by steamers.

Figures in the *New South Wales Statistical Register* for 1888 and 1900 show that sailing ships as a proportion of the total number of vessels entering NSW ports (including riverboats) fell from 23 per cent to 4 per cent.

As they became obsolete, sailing ships were often stripped down and turned into coal hulks, moored in major ports to form a reserve of bunker fuel. Pemberton (1979, p. 197) points out that 'international steamer routes were shaped by the location of coaling stops, and as trades diversified those ports that did not have local supplies very soon began to stockpile imported supplies.' Burley (1960, pp. 394–5) argues that 'the overseas trade in NSW coal developed primarily as a by-product of the operational needs of the British shipping industry ... exports from Australia to Europe were generally insufficient to take up all the ocean-going tonnage bringing imports to Australia' so ships carried Newcastle coal as an intermediate cargo to Asia, where they took on rice and other commodities for the European markets.

Given the prominence of shipping in the Australian transport task at the turn of the century, it is unfortunate that so little official statistical information is available on the energy used for the maritime transport task.

INTERNATIONAL SHIPPING

Ships' stores were recorded by colonial and state governments as general exports to other colonies and overseas countries until 1906 (*Official Year Book of the Commonwealth of Australia 1901–1907*, p. 497). It is therefore not possible to ascertain from official records the amount of coal bunkers taken on by foreign steam ships in Australian ports in 1900.

In New South Wales, 'up to the end of 1905, no record was kept of the quantity of bunker coal taken by the various steamers, and the amount was included with that used for home consumption. During 1906, it was ascertained that no less than 1 184 738 tons were exported as bunker coal' (*Official Year Book of NSW*, 1905–6, p. 694). The value of bunker coal exported from NSW in 1906 was £447 000 (*Official Year Book of the Commonwealth of Australia 1901–1907*, p. 425). That is, the value of coal exported as bunkers in 1906 from states other than NSW was £128 471.

It is not possible to determine how many foreign ships visited states other than NSW in 1906, because Australian ships were still classified as British, and British (ie United Kingdom) shipping played a dominant role in Australian trade at the time. Of all steamships (foreign and domestic) visiting Australian ports in 1906, 32 and 26 per cent chose ports in NSW and Victoria respectively (CBCS ?1910, table 14, p. 12). A further 14 per cent visited South Australia, and 10 per cent called at Queensland ports. However, Victoria matched NSW in economic activity (especially manufacturing) at the turn of the century, and it is likely that most foreign ships would have called there on a voyage to Australia. Because Victoria and South Australia obtained most of their black coal from NSW at that time, prices there were higher than in NSW, and probably higher than in Queensland and Western Australia, which had local sources. Whether steamship owners were sensitive enough to differentials in bunker prices to require vessels visiting Victoria or South Australia to coal up in Queensland or NSW is unknown, but it is not considered to have been likely, given the extra distance and time involved.

It has therefore been assumed that bunker coal taken on by foreign ships was obtained only in NSW and Victoria. That is, Victoria is assumed to have supplied £128 471 of coal to foreign vessels in 1906. It was also assumed that black coal, not local brown coal was sought by steamships. The price of NSW coal in 1906 was '15s. 5d. per ton in the [railway] trucks at the wharf [in Melbourne]' (*Royal Commission on the [Victorian] Coal Industry* 1906, p. xxxviii). Not included in this price is the 1s per ton wharfage charge that would have been levied by the Victorian Government when the coal was unloaded at the docks, but it is not clear how much additional cost was involved in loading the coal into the railway trucks. It was therefore decided to assume that 15s 5d. (185d) approximated the price of bunker coal at Victorian ports. On this basis, Victoria would have supplied 166 665 tons of coal to foreign vessels in 1906.

It is therefore estimated that total bunker coal supplied to foreign vessels in 1906 was in the order of 1 351 400 tons.

The total number of (foreign and domestic) steamships entering Australian ports in 1906 was 7406; and the number in 1900–01 was about 7000, assuming 600 for Queensland, for which data are available only from 1902–03 (CBCS, ?1910, table 18, p. 14). Assuming that the same proportionate increase also held for international ships alone, this represents an increase from 1901 to 1906 of almost 6 per cent. Applying this percentage as a scaling factor to the bunker coal export tonnage in 1906, it is estimated that foreign-trade vessels took on 1 277 316 tons of (black) bunker coal in Australian ports in 1900–01.

There was no cabotage policy regarding coastal shipping in 1901. Foreign vessels visiting Australia therefore often carried domestic cargo and passengers between Australian ports. It is not known what proportion of domestic cargo or passengers was carried by international shipping. It has been assumed arbitrarily that 10 per cent of coal bunkers taken on by international shipping should be attributed to the domestic transport task in 1900–01; that is, about 127 732 tons. The remaining 1 099 584 tons has been attributed to international shipping and is recorded separately from national emissions, in accordance with guidelines on bunker fuels issued by the International Panel on Climate Change (IPCC/OECD 1994).

COASTAL SHIPPING

Despite an extensive search of official data, no information was found to permit the accurate estimation of even the order of magnitude of coal bunkers used by Australian-based coastal shipping.

Page (1975, p. 156) records that testing in about 1900 by ships' engineers of the Adelaide Steamship Co. Ltd found that the '*Wollowra*' consumed 54.8 tons of Seaham coal in 24 hours travelling at 13 knots, with the percentage of ash produced being 18.8 per cent. The *'Investigator'* averaged 15.12 miles to the ton on Southern small coal; and the *'Ferret'* produced 22.43 miles per ton using Newcastle large and small coal. Evidence given by a Melbourne shipping agent in appendix A of the *Report from the [Commonwealth] Royal Commission on Ocean Shipping Service* (1906) indicates that an ocean-going vessel would require 900 tons of coal in 15 days (60 tons per day, similar to the rate for the *'Wollowra'*) to steam from Fremantle to Durban at 13 knots; but evidence in appendix G shows that although a ship travelling at 14 knots uses about 113 tons of coal per day, this amount rises more than proportionately with every unit increase in speed up to 360 tons per day for a 'First Class Mail Steamer' travelling at 20 knots.

Neither the total annual mileage of a typical coastal steam vessel nor its speed are known, so that the fuel intensities cited by Page and the Royal Commission cannot be used to estimate total coastal usage of coal.

The *Official Year Book of the Commonwealth 1901–1907*, pp. 528–540, records that 113 steamships (owned by 11 companies) engaged in regular interstate and coastal services in 1901 and for several years thereafter. The ships involved had a gross tonnage of 184 574 and a net tonnage of 114 080. The number of steam vessels on the registers of the various ports of the Commonwealth at the end of 1901 was 943, with a net tonnage of 203 541 and a gross tonnage of 329 316 {(184 574/114 080)*203 541}. Parsons (1981) provides detailed information only for coastal passenger steam and motor ships.

Foreign vessels visiting Australia in 1901 numbered about 3 890 and had a (gross?) tonnage of 6 340 000. CBCS (?1910, p. 15) shows that about 80 per cent of vessel numbers cleared in Commonwealth ports in 1901 were steam powered. Applying this proportion to foreign vessels, it is estimated that about 3112 steamships cleared Australian ports in 1901; and the commensurate tonnage was about 5 072 000. The amount of coal bunkers taken on by foreign ships was estimated above to be 1 277 216 tons.

The figure of 3112 foreign steam vessels that cleared Australian ports involves some double-counting, because some ships are likely to have entered and cleared more than one port. In the absence of any better figures, however, it can be regarded as a rough indicator of foreign ship 'activity'. The 'bunker/activity' ratio for foreign ships is thus about 410 tons of coal per 'activity'.

The number of all steam vessels (Australian-registered and foreign) cleared at Australian ports in 1901 was about 7 027 (assuming about 600 for Queensland ports). This leaves a residual 'activity' level of 7 027 minus 3 112 for Australian-registered ships only; that is, 3 915 port clearances. Applying the 'bunker/activity' ratio calculated for foreign ships, it is estimated that about

410*3915 = 1 605 150 tons of coal bunkers were used by Australian coastal shipping. Adding to this figure the 127 732 tons estimated to have been used for coastal trade by foreign ships in Australian waters provides an overall estimate of 1 732 882 tons of bunker coal used for the domestic shipping task in 1901.

GREENHOUSE EMISSIONS

As it was for railways, it was assumed that the appropriate energy content for bunker coal was that for 'unwashed steaming (black) coal'; given by Bush et al. (1993, p. 51) as 23.9 GJ/t. Assuming only a 95 per cent oxidation rate, and using the emission rates given in NGGIC (1994c pp. 11–12) for modern 'commercial' boilers, it was estimated that emissions of greenhouse gases were as given in table IV.1.

TABLE IV.1 GREENHOUSE GAS EMISSIONS[a] FROM THE AUSTRALIAN SHIPPING SECTOR 1900–01.

Task	*Coal (tons)*	*CO_2[b] (Mg)*	*CO (Mg)*	*CH_4[c] (Mg)*	*NO_x (Mg)*	*N_2O (Mg)*
Coastal trade						
Aust-reg ships	1 605 150	3 332 524	7 238	371 +419	8 760	2 388
Foreign ships	127 732	265 190	576	30 +33	697	190
Total attrib. to Aust.	1 732 882	3 597 714	7 814	401 +453	9 457	2 578
Intern. shipping task	1 099 584	2 282 900	4 959	254 +288	6 001	1 636

a. Emission factors as specified in NGGIC (1994c, p. 11–12). For non-CO_2 gases, commercial coal-fired boilers were assumed to be appropriate for conversion purposes.

b. Following conversion using 1 ton = 1.016 tonnes, the energy content of coal was estimated on the basis of 23.9 GJ/tonne specified by Bush et al. (1993, p. 51) for unwashed black coal.

c. Figure in first row is CH_4 generated from combustion (end-use) only. The second row is an estimate of CH_4 emissions released from coal seams during mining; based on NGGIC (1994d, p. 30), assuming one Class B (non-gassy) black coal mine for all 2 832 499 tons used by ships in 1900. Coal seam emissions have been allocated in proportion to share of coal used. (Full fuel cycle estimates of greenhouse emissions would include CH_4 from both combustion and coal seam emissions.) Class B mines were assumed because there was no information available for specific in situ seam methane content for mines.

Source Estimates in body of text of appendix IV.

APPENDIX V URBAN DENSITY AND TRANSPORT EMISSIONS

Long-term comparisons of urban densities are unlikely to be accurate.

Population figures are readily ascertainable, but the areas on which they are based are rarely consistent. For example, the Victorian Government Statist in 1887 calculated population densities by taking into account reserves such as parks (*Victorian Year-Book, 1887–88*, pp. 79–80). The CBCS (1917) reports results for Sydney for the 1911 Commonwealth census by local government area on the basis of municipalities and shires. It includes Ku Ring Gai (23 040 acres) as part of Sydney, giving a total metropolitan area of 118 299 acres. But the *New South Wales Statistical Register for 1900 and Previous Years* (1902, p. 6) gives the total metropolitan area for Sydney as 91 220 acres, defining local government areas by municipality and borough. Most of the difference is due to the exclusion of Ku Ring Gai from the tabulated results of the NSW state census, but even areas of individual suburbs differ. The areas in acres given by the Commonwealth 1911 and NSW 1901 censuses respectively for the first four suburbs listed alphabetically are Alexandria (1024, 1024), Annandale (360, 333), Ashfield (2061, 2048), and Balmain (932, 888). The ABS (1991) Commonwealth census figures for 1991, on the other hand, are based on statistical divisions that may not always correspond to local government areas.

In a detailed examination of Australian metropolitan population figures from the mid-nineteenth century, McCarty (1970) revises even the Commonwealth census figures of 1911. However, he does not provide figures for corresponding land areas to permit the calculation of densities.

Concepts of cities can change over time, and will depend on the perspective of the analyst. A major question in this regard from the viewpoint of a transport analyst is whether to include detached commuter suburbs, or even separate urban centres such as Bendigo, when looking at Melbourne. For example, Melbourne experienced shortages of fish and firewood in the late nineteenth century, and it was necessary to transport these two items by rail from outside the metropolitan area. From the point of view of urban freight transport it is a moot point whether transport of firewood and fish should be treated as part of the urban freight task or as rural freight, particularly if supplies came from the metropolitan periphery.

To avoid the need for lengthy recalculations of metropolitan and urban areas, it was decided to accept Commonwealth census data for 1911 and 1991 as being acceptable for the purposes of comparison of urban densities in about 1900 and 2000. Although the 1911 data are based on local government areas and the 1991 data are based on statistical areas, it was assumed that in both time periods those collecting the data sought to ensure that the data matched the contemporary concept of what constituted the 'organic' city; that is, that the concept matched intuitively the acceptable statistical definitions. It is recognised that inaccuracies may result from this seemingly naive approach, but these are comparatively minor in the context in which the figures are to be used.

Even accurately calculated urban densities are themselves only averages and are therefore a highly stylised means of representing transport demand within a city composed of suburbs of varying population densities. (An improved indicator could be calculated using a Gini coefficient of suburban or other area densities.) Urban densities can only provide one rough indicator of the travel task, and uncertainties as to the number of animals (for example) used for the urban transport task are themselves likely to swamp any inaccuracies in the average density figures used for each city.

Because the density figures in table V.1 are intended for use in representing transport demand within all Australian cities, a simple average of densities would have been inappropriate. The density for each capital city has therefore been weighted by that proportion of the population of all capital cities. The ratio of the average weighted density in 1991 to that of 1911 provides some indication of increased reliance on non-pedestrian transport within urban areas during the twentieth century.

Table V.2 estimates urban greenhouse emissions for 1988 and 2000 on the basis of information provided in BTCE (1995).

TABLE V.1 AUSTRALIAN URBAN DENSITIES[a], 1911 AND 1991

Variable	1911					1991				
	Metro pop.	*Area sq. km*[b]	*Density*	*% Aust metro pop.*	*Weighted density*[c]	*Metro pop*	*Area (sq. km)*	*Density*	*% Aust metro pop.*	*Weighted density*[c]
Melbourne	588 971	675	873	0.35	306	3 022 533	7 815	387	0.30	116
Sydney	629 503	479	1 314	0.37	486	3 538 448	12 381	286	0.35	100
Brisbane	139 480	807	173	0.08	14	1 334 098	4 972	268	0.13	35
Adelaide	189 646	609	311	0.11	34	1 023 546	1 918	534	0.10	53
Perth	106792	347	308	0.06	18	1143378	5457	210	0.11	23
Hobart	39937	238	168	0.02	3	181838	937	194	0.02	4
total	1694329	3155	537	1.00		10243841	33480	306	1.00	
average weighted density					144					55

a. Densities expressed as number of persons per square kilometre. Rounding errors exist for some totals.

b. Acreage given in source converted to square kilometres on the basis of 1 acre = 0.4047 hectares and 100 hectares = 1 square kilometre.

c. Density (number of persons per square kilometre) weighted by proportion of population in the capital city compared to total population in all capital cities. For example, Sydney in 1911 had a population density of 1314 persons per square kilometre and 35 per cent of the Australian metropolitan population: the product of these two factors yields a weighted density of 486.

Sources CBCS (1917, vol I, including appendices); ABS (1991).

TABLE V.2 GREENHOUSE EMISSIONS FROM URBAN TRANSPORT IN 1988 AND 2000

	Car	Bus	LCV	Rigid truck	Articulated truck	Rail
1988						
urban energy[a]	342.60	6.60	59.83	48.89	23.82	4.01
% total modal energy[b]	0.73	0.44	0.59	0.64	0.30	0.12
urban emissions[c]	32 776	545	5 197	3 578	2 046	1 059[g]
2000[d]						
urban energy[e]	387.9		91.1	46.0	20.8	
% total modal energy[b]	0.72		0.60	0.58	0.21	
urban emissions[f]	34 072		7 752	3 703	1 772	1 088[g]

Notes and sources

a. End-use values in PJ. Taken from tables IV.3 and IV.5 in BTCE (1995).

b. Urban PJ as percentage of urban and non-urban PJ.

c. Estimated in Gg of CO_2 equivalent on a full fuel cycle basis using tables 6.1, VIII.3, VIII.7, VIII.9 and IX.4 in BTCE (1995).

d. Cars include buses and motorcycles (unpublished BTCE estimates)

e. Values in PJ taken from tables IV.3 and IV.5 of BTCE (1995) for 1993, scaled up by a ratio of 2000:1993 in PJ taken from tables VIII.2, VIII.6, and IX.3.

f. As for c. above.

g. Passenger only. Percentage of total energy for mode calculated on full fuel cycle basis. Based on Apelbaum (1993) and tables 3.6 and IX.1 in BTCE (1995).

ABBREVIATIONS, SYMBOLS, UNITS AND CONVERSION FACTORS

The basic units used in the paper are joules (J), grams (g), metres (m) and litres (L). The main prefix and unit combinations are petajoules (PJ), kilowatt-hours (kWh) and Gigagrams (Gg).

The following units, symbols and conversion factors have also been used.

Acre = 0.4047 hectares (ha). 100 hectares = 1 sq. km.

Carbon dioxide (CO_2)

Carbon dioxide equivalents are values of direct and indirect greenhouse gases other than carbon dioxide, expressed in terms of their Global Warming Potential (GWP) relative to an equal mass of CO_2 over a given period of time.

carbon monoxide (CO)

foot(ft) = 0.3048 metres

GDP = Gross Domestic Product

giga (G) = 10^9

Global Warming Potential (GWP): an index, defined to be the atmospheric warming effect over a given period due to an emission of a particular gas, relative to an equal mass of CO_2. The values used in this paper for a 100-year time horizon were CO_2 (1.0), CH_4 (24.5), CO (1.0), N_2O (320), and NO_x (8).

Gross tonnage of a ship is the capacity in cubic feet of the spaces within the hull, and of the enclosed spaces above the deck available for cargo, stores, fuel, passengers and crew, with certain exceptions, divided by 100. (100 cu. ft of capacity = 1 gross ton).

horsepower (hp). Unless otherwise stated, horsepower units used in the text refer to nominal horsepower in the English system (33 000 ft-lb of work per minute); the electrical equivalent of 745.7 watts in the international system of units. The metric horsepower equals 4 500 kilogram-metres per minute, or 0.9863 hp. Horsepower at the output shaft of an engine is termed brake horsepower (bhp)or shaft horsepower. Horsepower of reciprocating engines is often expressed as indicated horsepower (ihp), which is determined from the pressure in the cylinders. Brake horsepower is less than indicated horsepower by the amount of power lost due to friction within the engine itself.

hours (h)

joule (J) = 0.239 calories = 0.7375 ft-lb

kilo (k) = 10^3

kilometre (km)

lb=pound

mega (M) = 10^6

methane (CH_4)

mile = 1.609 km

nitrous oxide (N_2O)

oxides of nitrogen other than N_2O (NO_x)

peta (P) = 10^{15}

pound (lb) = 0.454 kg

tera (T) = 10^{12}

ton (Imperial) = 1.016 tonnes

watt (W) = 1 joule/second. (1 watt-hour = 3600 joules)

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Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AGPS	Australian Government Publishing Service
BTCE	Bureau of Transport and Communications Economics
CBCS	Commonwealth Bureau of Census and Statistics
DEST	Department of Environment, Sport and Territories,
DPIE	Department of Primary Industries and Energy
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
n.d.	no date given
NGGIC	National Greenhouse Gas Inventory Committee
n.p.	no publisher identified
NSWDOA	New South Wales Department of Agriculture
OECD	Organisation for Economic Cooperation and Development
SSCTCI	Senate Standing Committee on Transport, Communications and Infrastructure
UNEP	United Nations Environmental Program
UNIDO	United Nations Industrial Development Organization
WMO	World Meteorological Organization

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