Urban Planning and Transport Paradigm Shifts for Surviving the Post-Petroleum Age in Cities

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ABSTRACT

Cities vary enormously in the amount of energy they use in passenger transport, especially private passenger transport. In a study of 100 cities worldwide, Atlanta, Georgia residents each consume annually an average of almost 103,000 MJ in private passenger transport energy (about 2,970 litres of gasoline equivalent), while at the other end of the spectrum in Ho Chi Minh City, the figure is a mere 922 MJ or 26 litres. In the developed world, where fairer comparisons can be made, US cities consume on average 60,000 MJ per capita per annum for private passenger transport (1,730 litres) while Australian and Canadian cities average about 31,000 MJ (895 litres). High income Asian cities such as Tokyo, as well as Western European cities, which are wealthier on average than their North American and Australian counterparts, consume only between 9,500 MJ (274 litres) and 15,700 MJ (452 litres) per capita respectively. The large sample of developing cities in the study average only about 6,500 MJ (187 litres). Urban development in the auto-dependent cities of North America and Australia clearly requires abundant and secure quantities of relatively cheap oil, without which these cities would begin to unravel, whereas other high income cities are not nearly so dependent on this non-renewable resource.

At the same time that the world approaches, or perhaps has already reached peak oil production (the "big rollover") and begins to decline in its output of this resource, newly industrialising nations are dramatically increasing their demand for oil. This growing gap between world oil demand and supply will usher in a period of radically more expensive transport fuel along with uncertainties in its supply due to potential economic decisions on the part of OPEC nations, political instability and possibly armed conflict as countries position themselves to maximise access to remaining reserves. Under this scenario all cities, but especially the auto-dependent ones, will be forced to grapple with how to minimise their consumption of oil and replace it with alternatives, in short how to survive the post-petroleum age.

This paper shows the nature of the transport energy problem facing urban environments through a series of comparative data on cities around the world. It argues that low density sprawling development without effective transit-oriented sub-centres, combined with a focus on private transport infrastructure rather than infrastructure for walking and cycling, are major reasons behind currently high levels of transport energy use in many cities and a significant reason why less developed cities with much lower levels of private transport energy use are rapidly motorising and increasing their oil demand. This paper argues that for auto-oriented cities to tackle the oil problem the key paradigm changes that are needed in urban planning and transport are:

• development of a network of effective neighbourhood centres (1 km radius) and town centres (3 km radius) built at a *minimum density* of 35 people plus jobs per ha. This will allow cities to maintain an overall average 1 hour travel time budget per person (Marchetti Constant) without excessive car use and effectively transform auto cities into a series of more manageable "transit cities", with each neighbourhood and town centre being a small "walking city". This will also have many positive urban design, amenity and liveability benefits.

• prioritising the development of fast, reliable and attractive transit, to link all centres together, with walking and cycling priority within the centres.

• a moratorium on all high capacity road expansion to meet traffic demand forecasts; the old paradigm that we always have to keep reducing or eliminating congestion to minimise oil use is challenged and refuted and congestion is shown to be an important factor in mitigating oil use, not increasing it.

• allocating nearly all transport infrastructure investment funds for transit, walking and cycling in order to re-balance the severely unbalanced transport systems in auto cities. The old paradigm that we need "balanced transport spending" today to achieve "balanced transport systems" tomorrow, needs to be replaced with the idea of "biased transport spending" towards non-auto modes to re-balance the system and make up for 60 years or more of neglect in most cities.

• dropping the idea that technological change in terms of new vehicles and fuels alone will save cities from the coming oil crisis. It is argued that only a combination of reduced transport energy demand through urban structural

change, as well as fuel conservation and oil replacement through technological change, will enable cities to survive the post-petroleum era.

• recognition that strategic changes in urban form are not any slower or more difficult to achieve than significant technological change.

INTRODUCTION

Given the widely accepted and imminent peaking of world oil demand or the "big rollover", it is imperative that cities tackle the issue of transport energy use. Urban transport systems are the most dependent and vulnerable of all sectors to rises in the price of oil and potential shortages. This paper examines a set of data on an international sample of 84 cities, 58 in developed countries and 26 in developing countries in order to better understand the range of urban transport and land use patterns that exist in the world today, the resulting energy consumption patterns in transport and some of the key factors that underpin these transport and energy use patterns. Highlighting the critical importance of urban form, primarily the density factor, and the role of transport infrastructure provision and policies towards congestion in determining transport patterns and energy use, it suggests how to reconstruct an automobile dependent city around a set of centres bound together by high quality transit. Such centres would form a series of transit cities within the metropolitan region, each one with greatly enhanced opportunities for walking, cycling and transit, allowing more people to maintain there daily travel time budget or Marchetti Constant of 1 hour without resorting to excessive car use and significantly reducing their dependence on oil.

It is suggested that in order for cities to adapt to the post-petroleum age, relying purely on technological fixes will not provide the needed changes. Rather it is argued that a combination of changes are needed to provide the essential paradigm shift for cities to fundamentally reduce car use:
• curtailing or scrapping high capacity road construction;
• dumping congestion relief programmes and recognising that congestion can help cities move in a positive direction with respect to reducing car use and energy consumption;
• prioritising the construction of speed competitive transit systems;
• integrating development around those transit systems, and;
• creating attractive conditions for walking and cycling through good urban design in and around centres, in effect making all centres small, contemporary "walking cities".

Technological changes in vehicles and fuels can occur in parallel with such broader urban systems changes and will be much more effective in the context of greatly reduced travel demand for private transport. It is argued that technological innovation is not a panacea to the energy problem in transport and that the time required to restructure cities for less car and energy use can be at least equal to or even less than the time required for significant technological changes in vehicles and fuels.

METHODOLOGY AND DATA SOURCES

The data in this paper are drawn from the *Millennium Cities Database for Sustainable Transport* compiled over three years by Kenworthy and Laube (2001) for the International Union (Association) of Public Transport (UITP) in Brussels. The database provides data on 100 cities on all continents, though 16 cities provide only partial data. Data summarised here represent averages from 84 of the fully completed cities (Table 1) in the USA, Australia and New Zealand, Canada, Western Europe, Asia (high and low income areas), Eastern Europe, the Middle East, Latin America, Africa and China.

<p align="center">**TAKE IN TABLE 1**</p>

The database contains data on 69 primary variables. The methodology of data collection for all variables was strictly controlled by agreed upon definitions contained in a technical booklet of over

100 pages and data were carefully checked and verified by three parties before being accepted into the database. A detailed discussion of methodology is not possible in this paper.

From these primary variables, some 230 standardised variables were calculated. Cities can thus be compared on urban form, private and public transport performance, overall mobility and modal split, private and public transport infrastructure, the economics of urban transport (operating and investment costs, revenues), passenger transport energy use and environmental factors. For this overview, which is focussed on transport energy use in cities, only a selection of the most relevant features was chosen for comment. Tables 2 to 5 provide comparative urban data on transport patterns, transport infrastructure, energy use and energy efficiency in cities, summarised according to the 11 areas shown in Table 1, divided into higher and lower income parts of the world. The data are for the year 1995. Data collection on these cities commenced in 1998 and was completed at the end of 2000. Thus data for 1995 provides the latest perspective that can reasonably be expected for a study of this magnitude undertaken at that time.

THE PEAKING OF GLOBAL OIL PRODUCTION

Urban automobile dependence, insights into which can be gained from the data in Tables 2 and 3, has large implications for energy use (these data and the energy data are discussed in the next section). In this new century, the world is going to have to face the reality that the assumption of cheap and easily available oil will no longer be valid. This change will affect every industry and aspect of life, e.g. food production and consumption, the automotive industries, land development patterns and how much private transport requirements are built into them, rising and unsustainable household expenses for transport and even perhaps the very survival of highly auto dependent cities or parts of cities (e.g. Motavalli, 2005; Green and Silverthorn, 2004). World oil production is predicted to peak by 2010 ("the big rollover") and then to enter a phase of irreversible decline, leading to shortage and supply interruptions, rapidly rising prices and a greater concentration of oil power in the Middle East. Some senior commentators in the field believe that world oil production may have already peaked, but this will probably not be known for sure for another 5 years, as was the case when US oil production peaked in 1970.

The peak in world oil production will have profound implications for transport, which is utterly dependent upon conventional oil and cannot restructure or alter its technologies overnight (Campbell, 1991; Campbell and Laherrere, 1995; Fleay, 1995). The relative certainty of peaking oil can be seen historically in the accuracy of M. King Hubbert's original prediction of the US oil production peak in 1970 (Hubbert's bubble) (Hubbert, 1965). He predicted in the 1950s and 60s that world oil production would peak shortly after the year 2000, which is now being confirmed by many people, based on much more comprehensive data, though there is still some dispute over the seriousness or immediacy of the problem (Motavalli, 2005).

COMPARATIVE URBAN TRANPORT PATTERNS, ENERGY USE AND MODAL ENERGY EFFICIENCY IN AN INTERNATIONAL SAMPLE OF CITIES

Car usage
The critical factor that underpins transport energy use is car use (Table 2 and 3). US cities 'require' over 18,000 car passenger kms per capita to meet the access needs and discretionary travel of their inhabitants. By contrast, their high-income counterparts in Europe and Asia have only between 20% and 63% of that level of use. In the lower income regions, car passenger kms per capita range from

a mere 814 (4% of the US figure) in Chinese cities, up to 3,300 in Middle Eastern cities (18% of the US figure).

In order to gain some insight into the degree of motorisation in cities around the world relative to their wealth or "capacity to pay", we can express the above car use figures as per dollar of their GDP. Average metropolitan GDP figures are shown for the respective regions in Tables 2 and 3. Amongst the wealthier cities, the US and ANZ cities are the leaders in car use relative to wealth with 578 and 576 car passenger kms per $1000 of GDP, with Canadian cities some way behind at 415. The Western European and prosperous Asian cities distinguish themselves in their significantly lower levels of private car mobility (193 and 114 car passenger kms per $1000 of GDP respectively).

In lower income cities the rates of private car mobility per unit of wealth are comparatively high. African cities have some 940 car passenger kms per $1000 of GDP, which is close to double the US and ANZ level. This effect seems to come from the South African cities where two clearly distinct transport systems exist side-by-side (the sizeable automobile-based system for prosperous people and the informal, public transport and walking-based systems for the vast majority of poorer residents). Latin American and Middle Eastern cities are virtually identical to the US and ANZ cities in this factor (580 and 595 respectively). In 1995, low-income Asian cities and Chinese cities (494 and 344 car passenger km per $1000) had already far exceeded their wealthy Asian neighbours (193) and even Western European cities in this factor (114).

It is clear that less wealthy cities, although far lower in their per capita car use than most higher income cities (except those in Asia), are experiencing comparatively high levels of car use in relation to their modest wealth as motorisation proceeds, in most cases, unrestrained.

Motor cycle usage
Usage of motor cycles is comparatively small in high-income cities. Motor cycle use, as a percentage of total private passenger kms, ranges from 0.25% in the US cities up to 9% in the high-income Asian cities (Tables 2 and 3). By contrast, in low income Asian cities and Chinese cities, motor cycle mobility represents 26% of private passenger kilometres, while in the other lower income regions it again is small, at between 0.7% and 3.8%. Again, if we normalise this by wealth, the huge commitment to motor cycles in low income Asian cities and Chinese cities is apparent (averaging 152 motor cycle passenger km per $1000 of GDP, while all the other regions average a meagre 10).

Why motor cycles have burgeoned to this extent in most Asian cities and in no other parts of the world (nor in Manila where motor cycle ownership is actually about half the US level), is an interesting policy question. The low penetration of motor cycles in Manila is possibly a result of the extensive and effective jeepney system and paratransit-like motorised tricycles (Barter, 1998). The role of motor cycles in urban transport, their potential to facilitate urban sprawl by providing low cost private transport to large numbers of people, and their environmental and human impacts, are important issues to understand. This is especially so in cities like Taipei where ownership is some 200 per 1000 people and usage represents 35% of private mobility. Notwithstanding this, they are the most energy-efficient form of private motorised mobility available.

TAKE IN TABLES 2 AND 3

Private motorised transport modal split

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The final variable that provides insight into private transport patterns is the percentage of all daily trips (all purposes) that are catered for by private transport (Tables 2 and 3). Not surprisingly, US (89%), ANZ (79%) and Canadian cities (81%) head the list. By contrast, their wealthier counterparts in Europe and Asia have only 50% and 42% respectively of all trips by private transport. In the lower income cities private transport caters for only between 16% (Chinese cities) and 36% (Asian cities) of all trips. The exception is the Middle Eastern cities where the proportion rises to 56%.

Despite the overwhelming visual and sensory impacts of traffic and its capacity to rapidly saturate the public space of a city, private transport is a minority player, relative to public transport and non-motorised modes, in 7 out of the 11 areas in this study. Because of their size, cars and other private transport vehicles have a huge impact, even at relatively low ownership levels, in urban environments not designed for them. This is true in most dense, rapidly developing cities in the world and, of course, it has enormous social justice and equity implications. If urban transport priorities are primarily directed towards facilitating car and motor cycle travel through new freeways, parking facilities and so on, then this can threaten public and non-motorised mobility, which operate at high energy efficiency and provide effective transport services to a high proportion of people.

Public transport usage levels
There are two clear extremes in public transport use. The US cities stand out globally with only 3% of daily trips, while Eastern European city residents use transit for 47% of all trips. The other high public transport modal split cities are high and low income Asian cities and Latin American cities. ANZ, Canadian and Middle Eastern cities are comparatively low public transport modal share cities. Western European cities have only 19% of daily trips on average by public transport, which is neither very low nor very high in this sample of cities.

Although some low-income cities enjoy comparatively healthy public transport use for their very low level of service (e.g. in China), this will not last. The crowded, unreliable and poor safety of public transport is something that people in such cities will try to escape at their first opportunity, given access to a car or motor cycle. Many low income cities may be unable to resist further rapid motorisation unless they improve the quality and speed-competitiveness of their public transport systems. This will generally mean developing more extensive rail systems, or fully segregated busways. If not, transport energy use is likely to rise rapidly.

Non-motorised modal split
The most egalitarian and sustainable modes of urban transport are foot and bicycle. These modes have few fossil fuel implications outside of the embodied energy in human food, bicycles and pedestrian and bicycle infrastructure. There is an extraordinary range in the use of these energy-efficient modes (Tables 2 and 3). In US cities, only 8% of all trips are made by foot and bicycle. Other auto cities are a little higher (respectively, 10% and 16% in Canadian and ANZ cities). Eastern and Western European, high and low income Asian, Middle Eastern and Latin American cities, all have very similar levels of non-motorised mode use, ranging from 26% to 32% of all trips. The African cities have 41% walking and cycling, due to the majority low-income populations who rely heavily on walking, while the world leader in 1995 was still the Chinese city with 65%.

It would appear very sensible for social, environmental and economic reasons, and certainly from an energy perspective, to prioritise the use of non-motorised modes by ensuring that facilities for them are actively promoted and not eroded by motorisation. This is especially urgent in rapidly developing cities, especially in China where their pedestrian and cycling advantage appears to be under

increasing threat from policies against bicycles and the sheer scale of motorisation (de Boom et al., 2001; Kenworthy and Hu, 2002; Kenworthy and Townsend, 2002).

Private passenger transport energy use
What are the transport energy use implications of these broad transport patterns in cities? Tables 4 and 5 reveal a very large range in transport energy consumption, with US cities leading the world at over 60,000 MJ per person per year of energy used for cars and motor cycles. This is twice as high as their nearest rivals, the Canadian and Australian cities, and four to six times more than their biggest competitors in the global economy, the western European and wealthy Asian cities, such as in Japan. Even cities in the oil-rich Middle East only use 10,600 MJ per person, despite some relatively conspicuous consumption in cities such as Riyadh (25,000 MJ per person). The three Chinese cities consume an average 2,500 MJ per person in private passenger transport, which means that an average US city of 400,000 people consumes in one year, the same amount as a Chinese mega-city of 10 million people.

Three groups of cities stand out as being the most intensive in passenger transport energy use relative to their wealth. These are the US and the Middle Eastern cities (1,900 MJ/$1000 of GDP), and the African cities (2,200), again highlighting the high consumption and private transport orientation of a wealthy minority against a backdrop of widespread poverty in African cities. The outstanding cities are again the Western European cities and wealthy Asian cities who consume only 489 and 303 MJ/$1,000 respectively, showing comparatively modest demand for transport energy relative to their level of economic development and their economic capacity to sustain considerably higher private transport orientation. All the other regions fall between these extremes with an average of 1,364 MJ/$1,000.

TAKE IN TABLES 4 AND 5

Figure 1 allows all the cities in this large global sample to be examined for their private transport energy usage per capita. It shows that Atlanta consumes over 100,000 MJ per capita annually or some 111 times the consumption of Ho Chi Minh City, the lowest consumer. Indeed, Atlanta residents consume over three times the amount of energy in private transport as the average Canadian or Australian city.

TAKE IN FIGURE 1

As countries stake out their claims on ever diminishing and more costly conventional oil, especially those who so far have not yet significantly shared the benefits that flow from this valuable non-renewable resource, oil is likely to become a major destabilising geo-political and economic issue. Oil is also likely to become a significant force in shaping urban development patterns, as it will no longer be economically or socially sustainable to create land use patterns that build in automobile dependence.

Public transport energy use
The use of energy in urban public transport systems (Tables 4 and 5) is small compared to private transport, regardless of the significance of the transport task undertaken by public transport, which varies widely, as already discussed. In the US, ANZ, Canadian, Western European and Middle Eastern cities, public transport energy use per capita does not exceed 7% of the combined private and public passenger transport energy use (average of 4%). The biggest contribution is in Latin American cities (23%), with the other five regions averaging 17%. Also, it should be noted that where rail is

extensively used, electricity is a major energy source for public transport, which is often generated without oil (gas, hydro-electric, nuclear), and of course can also come from renewable sources. Public transport operations can thus more easily weather the coming peak in oil production because their demand for energy is numerically very much lower and also in many cities, not as reliant on petroleum-based fuels.

Modal energy consumption differences between private and public transport
Tables 4 and 5 show how relatively energy-inefficient private transport is compared to public transport. Energy consumed per passenger km in public transport in all cities is between one-fifth and one-third that of private transport, the only exception being in the US cities where large buses dominate public transport and attempt to pick up thinly spread passengers in suburbs designed principally around the car. In US cities, public transport energy use per passenger kilometre stands at 65% that of cars. Part of the reason for this is that in US cities the public transport vehicles have the highest use of energy per vehicle kilometre of all cities (26 MJ/km, with most other regions under about 16 to 17 MJ/km, or as low as 10 MJ/km in African cities).

Examining the overall modal energy consumption of motorised transport in cities (private and public transport combined), Canadian cities are the least efficient at 3.5 MJ per passenger km, followed closely by US cities at 3.2 MJ per passenger km. This reflects the large vehicles in use in North American cities, especially 4WD sports utility vehicles, their low use of motor cycles and their high levels of private versus public mobility. The private vehicles in US and Canadian cities consume about 5 MJ/km, whereas most other regions are under 4 or even 3 MJ/km, despite generally worse levels of congestion in these latter areas.

By contrast to North America, ANZ cities average 2.4 MJ per passenger km for their total motorised passenger transport system, while all the lower income regions range between 0.9 (China) and 2.0 MJ per passenger km. All these lower income cities have a more significant role for energy-efficient public transport, some have high use of energy-efficient motor cycles and many operate fleets of mini-buses, which are relatively energy-efficient (especially with high loadings).

Energy consumption by different public transport modes
Modal energy use can be examined on a per vehicle km or per passenger km basis. The former is an indication of the inherent energy use of the particular vehicle, the technology it exploits and the environment in which it operates (congestion etc). In the case of rail modes, the data are reported on a per wagon km basis, not train km. Energy use per passenger km is an indication of the mode's efficiency in carrying people, based on the kind of loadings that the mode achieves in different cities. Tables 4 and 5 contain these data for buses, trams, light rail (LRT), metro systems, suburban rail and ferries. Not all modes are present in some regions and the averages for a particular mode are taken from the cities in the region where the mode is found. All energy data are based on end use or actual delivered operating energy.

It is difficult to discuss the energy use per vehicle kilometre for public transport modes in any detail because of the huge variety of vehicle types, sizes and ages that lie behind the averages. A few general points can be made.
• As with cars, buses in US and Canadian cities are the most energy consumptive (between 24 and 29 MJ/km, compared to an average of 16 MJ/km in all other regions and only 10 MJ/km in Chinese cities).
• Big differences occur in vehicular energy use in suburban rail operations depending on whether higher consumption diesel systems are present.

• There are 29 cases where rail modes are represented in the two tables and in 24 cases the energy use per vehicle km for the rail systems is lower than that of the respective bus system in the region.
• Ferries clearly have the highest use of energy per km due to the frictional forces involved in operating through water. However, there is a huge variation based on vessel size (e.g. double-deck ferries in Hong Kong and small long tail boats in Bangkok) and speed of operation. The average operational energy use across the nine regions where ferries exist is 277 MJ/km, but figures range from 846 in US cities to only 25 in low-income Asian cities.

More meaningful results can be obtained from energy use per passenger km because this takes into account vehicle loadings and is a measure of the success in public transport operations. It is also the only way to fairly compare public and private transport modal energy use.

• Except for trams and light rail in Eastern European cities, rail modes use less energy than buses per passenger km in each region.
• Across all regions buses average 1.05 MJ per passenger km. This is compared to 0.52 for trams, 0.56 for LRT, 0.46 for Metro and 0.61 for suburban rail. There is, on average, not a huge difference in energy consumption between the different rail modes, and on average, rail systems in cities use about half the energy of buses per passenger kilometre.
• Urban rail modes, taken together across regions, are on average 4.6 times less energy consuming than the average car (0.54 compared to 2.45 MJ/passenger km).
• The above averages do, however, mask some exceptional energy performance by specific rail modes in particular regions. For example, light rail in low-income Asian cities and metro systems in Chinese cities consume only 0.05 MJ/passenger km. This is 57 times more efficient than an American urban bus and 76 times more efficient than a Canadian car per passenger km. These high efficiencies are mainly due to some exceptional loading levels on Chinese systems.
• In every region, ferries are by far the most energy consumptive public transport mode. In fact, in 6 out of the 9 regions where ferries are featured, their energy use per passenger kilometre exceeds that of private transport, though they represent strategic transport links, which if not there, would result in much greater private transport fuel use.

SOME KEY FACTORS UNDERLYING TRANSPORT ENERGY USE PATTERNS IN CITIES

Tables 2 and 3 contain some further data that help to explain the transport and energy use patterns just elaborated.

Urban form
The first and most important is the urban density data, which are very important in explaining transport patterns, especially car use (Thomson, 1977; Newman and Kenworthy, 1989, 1999a; Kenworthy and Laube, 1999; Cervero, 1995, 1998; Holtzclaw, 1990, 1994; Naess, 1993a,b). If we correlate urban density data for the 58 wealthier cities with passenger car passenger kms per capita from Kenworthy and Laube (2001), urban density explains 84% of the variance (Figure 2) and in the more heterogeneous low income sample it explains 47%. Similar correlations occur with private transport energy use per capita, all showing that as density increases, car use and energy use decline very significantly. The auto cities in North America and Australia/New Zealand are clearly the lowest density in the world and have the highest car use and energy use. Globally, the lower income cities are clearly denser than their wealthier counterparts (the clusters average 109 per ha, compared to the wealthier five clusters averaging 52 per ha). They contain the densest cities in the global sample (Ho Chi Minh City 356 per ha, Mumbai 337), although Hong Kong at 320 per ha, which in

the high income Asian group, is also exceptional. Cities throughout Asia, whether wealthy or not, are universally high density (average of over 160 per ha).

Increasing urban density is therefore a critical factor in shifting auto-oriented cities towards more sustainable levels of car use and energy use. Just how such density increases should be achieved is a key question for such cities and is explored later in the paper.

TAKE IN FIGURE 2

Transport infrastructure
Urban freeways: It has been understood since the 1970s, how urban freeway provision is directly associated with higher car and energy use in cities (e.g. Watt and Ayres, 1974). The mechanism for this, in terms of longer travel distances rather than savings in time, has been explained elsewhere (e.g. Newman and Kenworthy, 1984, 1988, 1999b). US cities, without any surprise, have the highest availability of freeway per person in the world, followed by ANZ and Canadian cities with 83% and 78% as much respectively. Outside of these three regions freeway provision falls away rapidly, especially in Latin American and Chinese cities (only 2% of the US level). The other 8 regions altogether average only 0.028 metres of freeway per capita, compared to 0.156 in US cities (18% of the US level).

It is not surprising that cities with the highest freeway provision also have the highest average speed of general traffic (44 to 49 km/h in US, ANZ and Canadian cities). The other cities with considerably lower freeway provision achieve only 29 km/h average road system speed.
Lower income cities have marginally higher provision of freeways per $1000 of GDP than high-income cities (4.5 km compared to 4.1 km). In fact, Eastern European, Middle Eastern and African cities exceed the US figure in kilometres of freeway per $1000 of GDP. Poorer cities appear to be giving priority to freeway construction and are reaching higher levels of motorisation than one would expect based purely on wealth.

Public transport infrastructure: Western European, high income Asian and Eastern European cities, and to a lesser extent the ANZ cities, are the only regions that have significant reserved alignments for public transport. This consists mainly of railways, but also a few physically segregated busways. All of the lower income city groups, apart from Eastern Europe, have comparatively scarce reserved public transport right-of-way. Chinese cities stand out as being particularly low in this factor and in the wealthier auto-dependent groups, US cities are clearly the lowest in segregated public transport right-of-way, though Canadian cities are not far behind. The data highlight that the wealthier regions have an edge in the provision of better quality public transport systems, with an average of 113 metres per 1000 persons of reserved public transport routes compared to 49 metres in lower income cities.

Congestion: Freeways and congestion issues are often linked together in discussions, especially in relation to efforts to save energy. Increasing urban traffic congestion is frequently cited as being responsible for huge wastage of energy in cities. The results in this study run directly counter to this assertion. They suggest that as congestion increases, there is less car use, more motor cycle use, more public transport use and more use of non-motorised modes. Conversely, lower congestion reflected in higher average speed of traffic, is associated with the direct opposite of this. Figures 3 and 4 demonstrate these points showing how car use per capita in cities around the world increases as the average speed of traffic increases (i.e. as congestion is reduced) and how public transport use is higher the more congested is the city.

The results suggest that congestion acts as a brake on car use. Congestion encourages greater motor cycle use, and works in favour of public transport, but only where these options offer speed advantages over cars in congested conditions, and where parking is limited. This is often the case in more congested high-income cities, since they commonly have urban rail systems, or less frequently, busways. Such speed advantages to public transport occur on specific corridors and especially with urban rail systems where in every group except African cities, suburban rail system speed exceeds that of road traffic, often by a big margin (some metro systems also exceed traffic speed). However, as the data in Tables 2 and 3 show, it is only in the high income Asian cities that system-wide public transport speed exceeds that of road traffic. In all other groups of cities overall public transport system speed is significantly below that of general road traffic. This highlights in particular the need to improve operating speeds of buses, which are all always well below general road traffic speed. This means developing more dedicated rights-of-way for this mode and giving less priority to major new road construction.

Overall, the results suggest that rather than saving energy, reduced congestion, reflected in higher traffic speeds, increases energy use. Higher traffic speeds favour cars, increase urban sprawl and travel distances, and reduce the viability of other modes. Speed is not used to save time, it is used to travel further. Cities should not be in any rush to reduce congestion in order to decrease energy use. Rather they should be strategically improving the public transport and non-motorised mode alternatives to help travellers avoid congestion.

Importance of rail and comparative modal speeds: The data in this paper highlight the importance of urban rail systems in developing competitive public transport systems and reducing energy use. Not only are they the most energy-efficient modes, but they are the most effective at capturing modal share from private transport. In the high income cities, only the European and Asian cities have public transport systems that capture a healthy share of the overall transport market and these are the cities where urban rail systems are most developed, especially in relation to their private transport equivalent, the urban freeway. The ratio of fully segregated public transport right-of-way to urban freeways in these rail-oriented cities is over 3 compared, to 0.4 and 0.5 in US and Canadian cities and 2 in ANZ cities. In the lower income sample, by far the healthiest public transport use is in the Eastern European cities where segregated public transport right-of-way is some 9 times greater than urban freeways.

Whilst there are cities in Latin America, Africa and China that achieve significant public transport use with little or no rail systems, they rely mostly on poor 'captive' riders. As already suggested, as incomes rise and car ownership levels grow, the public transport systems of these low-income, bus-based cities will tend to lose market share, because they cannot compete in speed or comfort with private transport. Motor cycles in particular tend to compete heavily with bus systems that are engulfed in traffic (Barter, 1998).

This is seen in the comparative modal operating speeds. There are no regions where the average speed of bus systems exceeds 26 km/h and the overall average across the 11 regions is only 19 km/h. In Chinese cities buses operate at an average 12.5 km/h, or about the same speed as cycling. On the other hand, metro systems operate between 30 and 37 km/h (average 34 km/h). Suburban rail systems across the regions average 42.9 km/h. When these speeds are compared to general road

traffic speed, which averages 34 km/h across all regions, it can be seen that only rail systems can compete.

Cities wishing to protect, rebuild and grow their public transport base, save energy (and reduce CO_2 emissions) as incomes rise and competition from motor cycles and automobiles escalates, need to seriously consider some form of segregated rail system. At the very least, cities need effective busways or Bus Rapid Transit (BRT) systems as demonstrated in Curitiba and São Paulo, and more recently, the Transmilenio BRT system in Bogota. Competitive transit speeds appear to be critical for public transport in any city.

Parking: Parking in the central business districts (CBD) of cities is another indicator of private transport infrastructure, which varies dramatically across regions. Parking supply in the CBD is an important factor in determining modal split for trips to these space-constrained areas of cities. The availability of parking, much more than price, tends to determine the attractiveness of car commuting to the central city. High levels of parking will encourage the most energy consuming trips to work, while well-loaded, radial rail systems will use the least energy.

The highest providers of parking are the US, ANZ and, perhaps surprisingly, the Middle Eastern cities, all having over 1 parking space for every 2 jobs in the CBD. By contrast, Chinese, Eastern European and Latin American cities average 17, 75 and 90 spaces per 1000 jobs respectively, with Canadian cities at 390.

In summary, the evidence suggests that reducing per capita transport energy use by building more private transport infrastructure is a vain hope. Rather it suggests a need to prioritise the development of fast, reliable and attractive transit and a moratorium on all high capacity road expansion to meet traffic demand forecasts. The old paradigm that we always have to keep reducing or eliminating congestion to minimise oil use is refuted by the data in this paper. Rather, congestion is shown to be a factor in mitigating oil use, not increasing it.

The data also suggest a need for a significant period where nearly all available transport infrastructure investment funds are spent on transit, walking and cycling infrastructure in order to re-balance the severely unbalanced transport systems in auto cities. The old paradigm that we need "balanced transport spending" today to achieve "balanced transport systems" tomorrow, needs to be replaced with the idea of "biased transport spending" towards non-auto modes to re-balance the system and make up for 60 years or more of neglect of these modes in most cities.

RECONSTRUCTING THE AUTOMOBILE CITY FOR THE POST-PETROLEUM AGE

The transport-activity intensity nexus
The previous discussion has highlighted, amongst other things, the importance of urban density and transport infrastructure in influencing private transport use and energy consumption in transport. In particular, the role of urban density and the provision of speed-competitive public transport systems as opposed to freeways, have been highlighted. This section highlights how these two key factors can be brought together to form a strategy for reconstructing car dependent, energy intensive auto cities into more sustainable forms.

The link between urban intensity and automobile dependence has been confirmed both between cities, as shown previously in Figure 2, and it has also been demonstrated within cities. The vertical axis can be car use or it can be transport energy use and the horizontal axis can be population per

urban hectare or jobs per urban hectare or both together – called activity intensity. The same shaped graph emerges. Figure 5 shows activity intensity versus per capita energy consumption in private transport for 58 cities around the world and Figure 6 shows the same data for local government areas comprising the Sydney metropolitan region.

The point on the graph where rapid acceleration in car usage appears to occur seems to be around 35 people and jobs per hectare; the error band is around 30 to 40 per ha.[1] This same critical density figure, below which automobile dependence increases dramatically, has been noted in many studies (e.g. Calthorpe, 1993; Holtzclaw et al, 2002; INRETS, 1995; Holtzclaw, 1990; Naess, 1993 a, b).

TAKE IN FIGURES 5 AND 6

Jeffrey Zupan, quoted in Owen (2004), states the following about the idea of a critical threshold density:

"The basic point is that you need density to support public transit. In all cities, not just in New York, once you get above a certain density two things happen. First, you get less travel by mechanical means, which is another way of saying you get more people walking and biking; and second, you get a decrease in trips by auto and an increase in trips by transit. That threshold tends to be around seven dwellings per acre. Once you cross that line, a bus company can put buses out there, because they know they're going to have enough passengers to support a reasonable frequency of service"

Seven dwellings per acre at a reasonable dwelling occupancy is equivalent to around 35 to 40 persons per hectare.

The Marchetti Constant or daily travel time budget and its link to physical planning
Although many discussions have tried to explain transport in non-land-use terms (e.g. Brindle, 1996; Mindali et al, 2004), the data suggest that the physical layout of a city does have a fundamental impact on movement patterns. So what is behind this relationship between transport and activity intensity? We have suggested (Newman and Kenworthy, 2006) that the relationship can be understood in terms of the Marchetti Constant. The Marchetti Constant explains how cities throughout history have functioned on the basis of an average one hour per day travel-time budget (Marchetti, 1994). Overcoming automobile dependence thus becomes a question of whether people can access the amenities of a city without a car. In particular for a centre, it becomes whether the time available for travel is less than the time it would take to access their centre using a bike, walking or riding public transit.

We show that if car dependence is to be overcome, then the critical design element becomes the diversity of urban amenities, which must be created within the Pedestrian Shed or Ped Shed of a centre to avoid making a car a necessity. Two types of centres are critical for cities. The **Local Centre** is essentially a Transit-Oriented Development with sufficient intensity of activity to enable it to be an effective and viable transit centre, supported by local services that bring people there as part of its multiple urban functions. The **Town Centre, (Regional Centre or Sub Centre)** is a place providing viable services for a region within a city. The Local Centre is defined by its Ped Shed of

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[1] Note that the density figures referred to here are genuine "urban density", in that they use total urbanised land as the denominator (residential, commercial, industrial land, local parks and open spaces, plus roads and any other urban land uses). The denominator excludes large areas of undeveloped land such as urban zoned, yet to be developed land, regional scale open spaces, agriculture and forestry land etc. The relationships shown in this paper will not occur with other measures of density such as residential density because this does not include road space and other urban activities, hence these are less relevant to transport issues.

about 1 km, or 10 minutes walking time, and the Regional Centre by its 3 km or 30-minute walking radius, or Ped Shed. The latter is an area that can be reached by walking for most urban services, but it also means that these services can be reached by a short bike, bus or car trip, i.e. the services are not dependent on car access.

We have suggested that both local centres and town centres must achieve the critical threshold density of 35 persons plus jobs per ha shown in the graphs to have any hope of not being totally dependent on the car. This means certain minimum or threshold numbers of residents and jobs are needed within the walking catchments or Ped Sheds of both types of centres. For a local centre with a Ped Shed area of 300 ha, around 10,000 residents plus jobs are needed within this 10-minute walking area. For a town centre of 3000 ha, approximately 100,000 residents and jobs are required within this 30-minute walking area.

At such minimum or higher densities, the amenities of a city can be provided, public transport, walking and cycling become viable within the daily travel time budget of about 1 hour, and car-dependence is sharply diminished. Such centres would also be characterised by strong legibility and permeability of street networks to facilitate direct routes for walking and cycling and ease of access by public transport. They would become more human in scale and their public realms would not be dominated by cars, roads and parking. In effect, these centres would all become contemporary examples of the historical walking city.

Putting it all together
Cities across North America and Australia that built in car dependence over the past 50 years are now trying to transform their urban environments into places where more transport options are available for the future. This usually involves developing new or refurbished transit systems, generally rail, and a set of centres to focus urban activity. However, one new rail line and a few centres are unlikely to significantly change a city because they lack sufficient coverage. However, based on the Marchetti idea, it is possible to restructure the expanses of an automobile city into a series of transit cities that are linked together with high quality speed-competitive rail transit. Transit cities are 20 to 30 kilometres across (based on typical overall transit operating speeds of 20 to 30 km/h), with a rail and bus service that feeds into a Town Centre lying at their heart. Along the lines feeding in to the Town Centre, which might be buses running on dedicated rights-of-way or LRT, would be a series of Local Centres. The whole region would be made up of a series of these transit cities joined together and linked by a fast rail service. Most people in the city could then live within the framework of local services in their Local Centre, or have easy access to an adjoining local centre. Main services, including work, would generally be located in the Town Centre. Some higher level services will always be in other Town Centres, especially the historic Central Business District, and these would typically be easily accessible by rail. However, the key to sustainability is to generate these Local Centres and Town Centres as genuinely viable, attractive and more people-oriented places in each of the transit city sections comprising the majority of the city-region. Walking and cycling within such centres would be priority modes and the urban design of centres would be to maximise their use.

This has recently been applied to the development of the Metropolitan Plan for the Sydney Region (www.dipnr.nsw.gov.au) where it is possible to see six distinct transit cities, each around 20 to 30 kilometres across and each having a major Town Centre and a series of Local Centres. This is shown conceptually in Figure 7. By focusing the plan on these six areas and knowing the kind of intensity of activity that could make them viable, it becomes feasible to determine where to direct growth and

where new transit infrastructure will assist the development of a more sustainable, energy-efficient city.

In many ways, the evolution of the city into the kind of polycentric structure described here is a natural urban systems response to the need to maintain the Marchetti Constant and is happening in many cities such as Vancouver, Sydney, Portland and even Perth. In this sense it is a response to the problem of traffic congestion where most cities find it simply impossible or downright self-destructive to be trying to maintain this constant by building more and more high capacity roads to keep acceptable access time to work and other urban amenities. Rather, the city tends to "morph" into a new form to ensure that it remains functional and liveable.

SOLVING THE ENERGY PROBLEM IN TRANSPORT IN THE POST-PETROLEUM AGE CITY

The energy data presented earlier in this paper show that there are very large differences in the energy consumption levels between private and public transport, with public transport systems and especially urban rail systems offering dramatically greater energy efficiency than any private transport fleet in any city today. Clearly, the substitution of private transport passenger kilometres for public transport passenger kilometres has very large potential to save energy. This is enhanced by the fact that it has also been shown that there is a "transit leverage" effect at work in cities whereby one 1 kilometre of travel by public transport replaces between 9 and 12 kilometres of car travel in US cities (Neff, 1996). Globally "this appears to be more like between 5 and 7 to 1, based on the relative decline in vehicle kilometers travelled per capita for every passenger kilometer travelled per capita on transit."(Newman and Kenworthy, 1999a, p.87). Of course, the substitution of car travel for walking and cycling has enormous energy conservation potential as well. More compact, mixed use urban form that creates much shorter travel distances, as suggested in the previous section, would make such substitution more feasible.

Of course, there is a view that the energy problem in transport can be solved primarily by technological means. This can involve the development of smaller, more fuel-efficient conventional internal combustion engine cars, new fuels to substitute for conventional oil, new energy systems for cars such as electric, hybrid or fuel cell vehicles or the development of radical new car designs such as Amory Lovins' "Hypercar". Such a single-sighted approach is not supported in this paper for a number of reasons:

• From a more holistic urban viewpoint, the less car use in a city, the more manageable and liveable is the city, regardless of the type of car or how it is fuelled. This is because energy and emissions are only two of the car's many problems. The most intractable problem is its space demands for movement and storage and the resulting impacts on the public realm of cities, especially the quality of the environment for pedestrians and cyclists. Car-based cities are not on a human scale and cannot deliver the quality public environments characteristic of, for example, many European cities (Beatley, 2000). The centres proposed in this paper cannot be achieved where cars are the dominant mode, regardless of fuel type or efficiency.

• More efficient cars or ones that run on new sources of potentially cheaper energy can actually encourage extra car use. As stated by Newman and Kenworthy (1999a, p.142), "The problem with technological solutions is that they invariably forget the Jevons Principle. This principle was first enunciated in 1865 by the economist Jevons, who predicted that making coal burning more efficient

would lead to more coal use as the efficiencies would lead to more economic uses of coal." Extra car ownership and use can exacerbate a whole range of other problems such as safety, sprawl-related social isolation and lack of community, the proliferation of non-human scale environments unsuitable for non-motorised modes, further marginalisaton of public transport systems and of course destruction of natural areas and productive food growing land. The energy problem must be tackled in a way that recognises and helps to address the many other problems of the car in cities.

• Technological change is by no means instantaneous. The infrastructure systems that cities have built around internal combustion engine cars running on conventional oil are immense, as are the fleets of vehicles that need to be replaced. The penetration rate of new technologies is invariably slow and requires multiple hundreds of billions of dollars to achieve the changes to factories producing the new cars, fuel distribution systems, support industries, retraining programmes etc. So far such changes have been very minimal.

• One of the arguments used against land use change as a way of mitigating dependence on cars and tackling the energy problem is that the time required to effect significant change is very long, because urban systems change very slowly, whereas technological change can be introduced more rapidly. However, the time required for significant land use change and development of extensive new public transport systems can, in reality, be even less than that of technological change.

For example, in the space of 20 years the Vancouver metropolitan region has constructed a large new automated rail system that has led to very substantial high density, mixed use sub-centre development, which in turn has helped it to begin to change the region into a more sustainable form. Massive redevelopment of central and inner city land uses such as at False Creek and Coal Harbor have occurred over a slightly longer period allowing tens of thousands of people to lead a less car-dependent existence. During the same period from 1986 to 2006, the changes in vehicle technology and fuels has had a virtually negligible effect on fleet fuel consumption, notwithstanding the fact that much larger vehicles today are achieving similar rates of fuel use as much smaller vehicles decades ago.

From the initial vision in the mid-1970s Portland, Oregon scrapped a major planned freeway and instead has progressively constructed an extensive LRT system (first line opened in 1986) and separate inner city tram system. It has at the same time radically transformed its central area into a highly livable, people-oriented place, pulling down an elevated freeway, transforming car parks into public squares and focussing the majority of new development in the last 20 years around urban rail, thus helping to contain sprawl. The technologies for cars and fuels over the same period, although having improved, have not been able to have any real effect on fuel use because people are driving further, thus overriding any enhanced technological efficiencies.

Perth, Australia since 1988 has electrified its entire train system, constructed a new 36 km line to the northern suburbs and will open a 74 km southern extension in July 2007. Urban rail use has more than quadrupled and is set to more than double again. Many examples of new transit-oriented developments have taken shape over the same period and many more are planned, These are helping to contain urban sprawl and beginning to create a more transit-oriented urban form for the city, allowing more and more people, even in distant outer areas to be less dependent on cars. Though the major policy response in Australia over the last 30 years to the need to save fuel in transport has been to improve the technology of vehicles, the average fleet fuel consumption of cars in Perth and Australia-wide has remained virtually unchanged from what it was in the 1960s. In 1963 it was 11.4 litres per 100 km and in 1995 it was 11.5 litres per 100 km (Laird et al, 2001, p.86). Relative gains

in fuel efficiency through better technology have been eaten up by more power consuming items such as power steering and air conditioning and increased weight.

There are many other examples of significant and rapid trends in land use change, such as the revitalisation of downtown areas across the United States and Canada (e.g. Toronto) bringing hundreds of thousands of people closer to work and other destinations available as short walking trips (Nowlan and Stewart, 1992). At the same time it is difficult to find any significant progress in the overall fuel-efficiency of vehicle fleets, notwithstanding improved technologies in cars and the gradual appearance of small numbers of electric and hybrid vehicles in cities.

Reconstructing cities to be more sustainable from a transport and energy perspective is clearly a long term project but can proceed at a significant rate when priority is given to it. Technological changes to improve vehicles and fuels should proceed in parallel with such changes but should not be seen as a panacea to the transport energy problem or as a soft option that avoids the need to address the structure of the city and the modes of transport available to people.

CONCLUSIONS

Cities around the world vary enormously in their transport patterns, energy use, infrastructure systems and urban form. Low density land use patterns, priority to freeway provision over speed competitive transit systems and policies that treat congestion always as a negative to be removed, are significant factors in understanding transport and energy use patterns.

Many cities today are responding to the imperative to reduce automobile dependence through changes in transport policies that are generating attractive and well-utilised public transport systems and significant changes in land use and urban form in the form of central and inner area revitalisation and TOD around transit stations. Such changes are conforming largely to the conceptual model in this paper of how to reconstruct the automobile city into a series of transit cities based around town centres and local centres, which give priority to non-motorised modes and are linked together by a fast rail service and fed internally by a network of buses and/or trams and LRT. It appears that such new transit cities may be a natural urban systems response to growing congestion and the impossibility of building more and more roads to relieve it. These land use and transport infrastructure changes are allowing cities to maintain the historically robust daily travel time budget of 1 hour (Marchetti Constant) by allowing more and more people to use walking, cycling and public transport to meet their daily needs within this travel time budget.

Such large scale changes to the structure of cities occur and have been occurring over relatively short time periods (10 to 20 years), allowing cities to reduce the growth in automobile dependence and energy use, whereas the long term policy in many cities to save energy or expand fuel options through technological fixes has produced almost no tangible changes to date.

If cities are to achieve paradigm shifts to confront the post-petroleum era they are going to need to recognise that technology is not a panacea but only one factor in the bigger venture of fundamentally restructuring cities to reduce automobile dependence and creating overall more sustainable and liveable cities. The energy issue must be seen as just one of a multitude of problems of the automobile city that need to be solved simultaneously through urban planning, transport planning, urban design and technological change.

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Private Passenger Transport Energy Use per Person, 1995
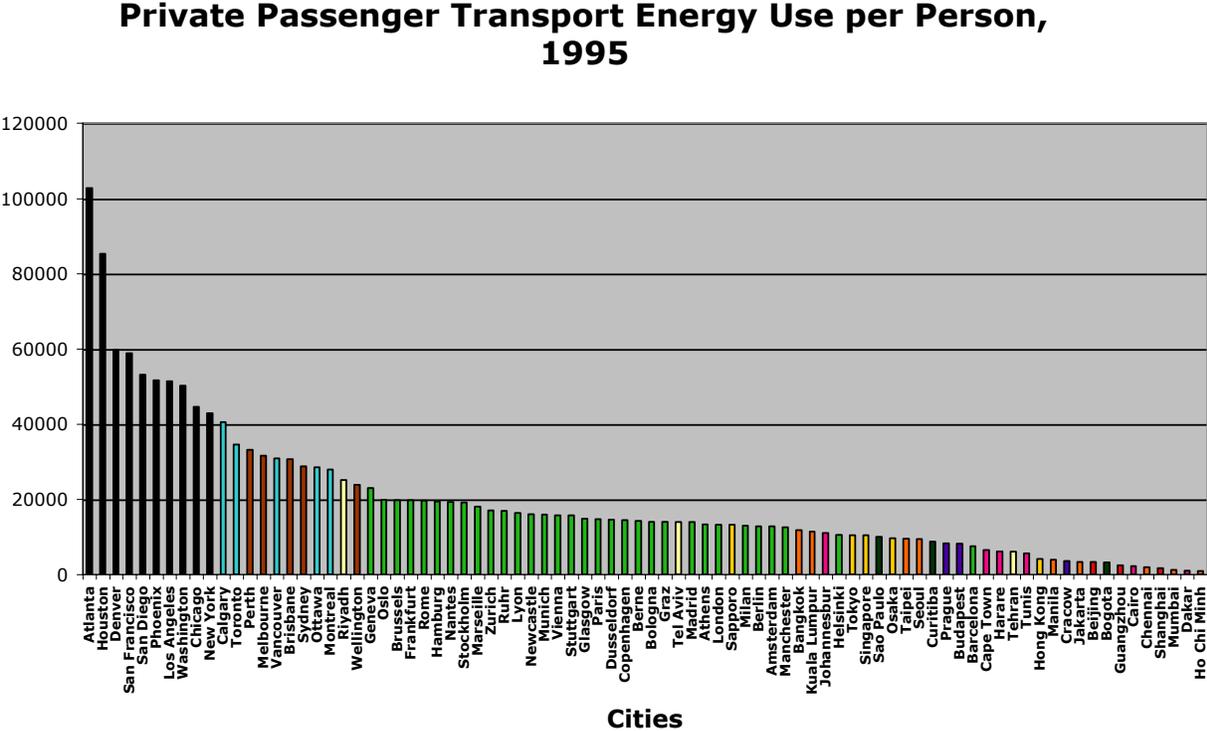
Figure 1. Private transport energy use per capita in 84 cities, 1995.

URBAN DENSITY VERSUS PRIVATE CAR TRAVEL IN 58 HIGHER INCOME CITIES

$y = 84197x^{-0.6713}$

$R^2 = 0.8392$

URBAN DENSITY (PERSONS PER HA)
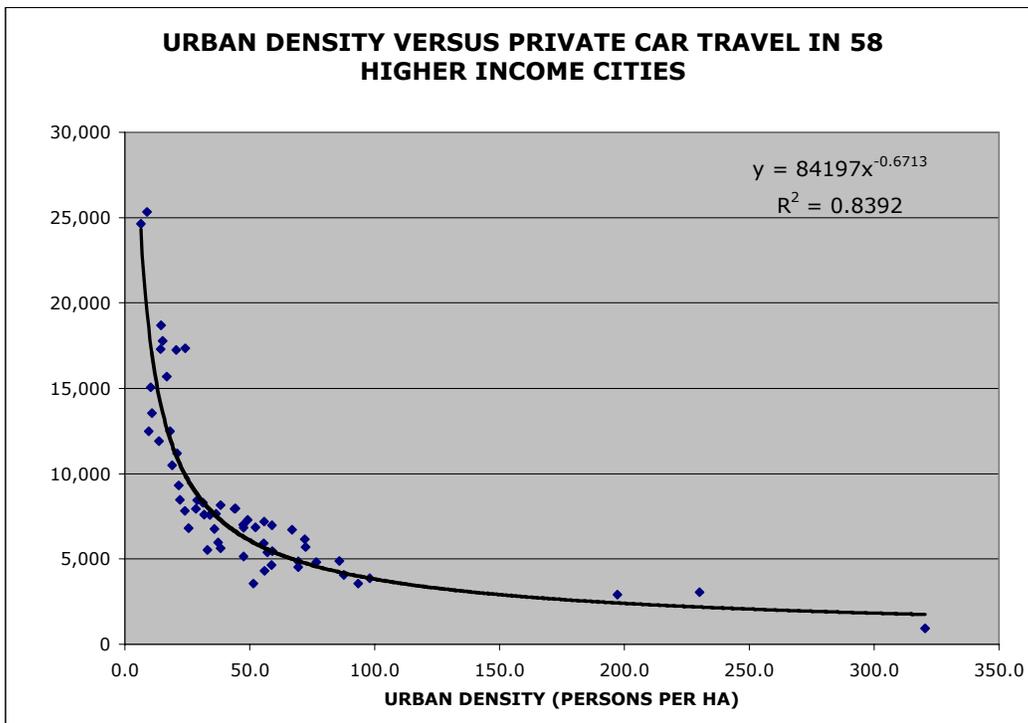
Figure 2. Urban density versus per capita car use in 58 higher income cities, 1995.

AVERAGE ROAD TRAFFIC SPEED VERSUS PER CAPITA CAR USE

ANNUAL PER CAPITA CAR PASSENGER KMS

$y = 420.75x - 7024.6$

$R^2 = 0.5923$

AVERAGE TRAFFIC SPEED (KM/H)
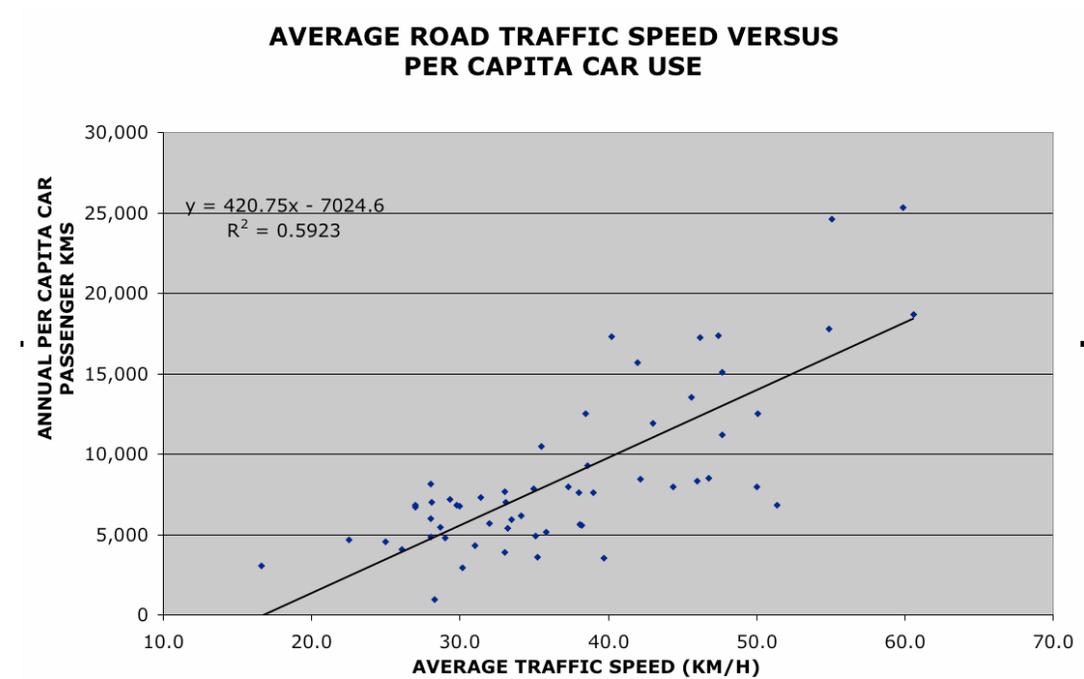
Figure 3. Average road traffic speed versus per capita car use in 58 higher income cities, 1995.

AVERAGE SPEED OF ROAD TRAFFIC VERSUS PER CAPITA PUBLIC TRANSPORT USE

$y = 2168.8e^{-0.067x}$
$R^2 = 0.5379$
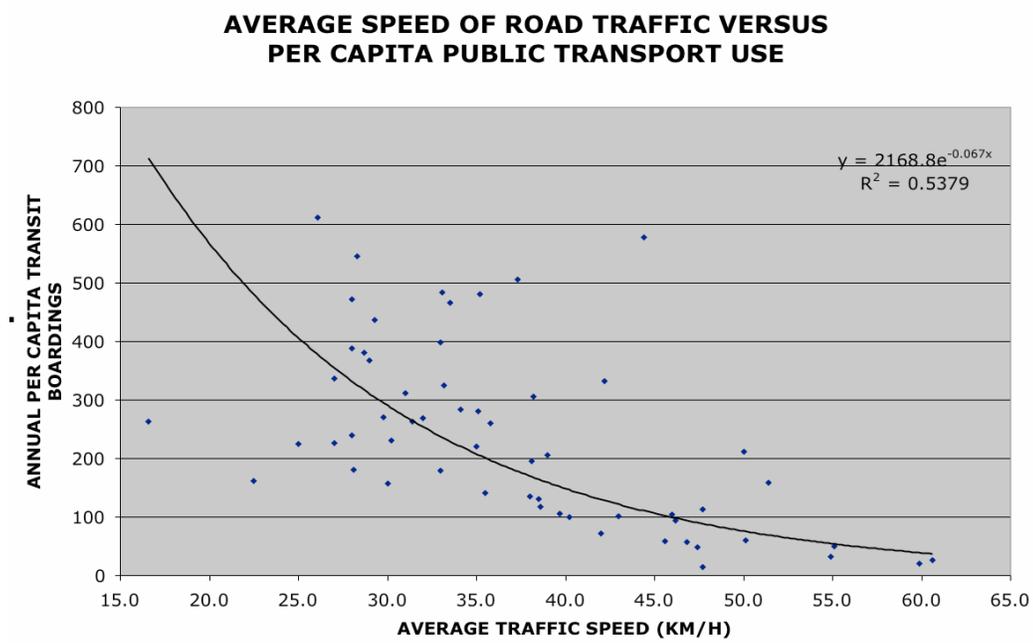
Figure 4. Average road traffic speed versus per capita public transport use in 58 higher income cities, 1995.

ACTIVITY INTENSITY VERSUS PRIVATE PASSENGER TRANSPORT ENERGY USE PER CAPITA

$y = 334752x^{-0.6925}$
$R^2 = 0.7697$
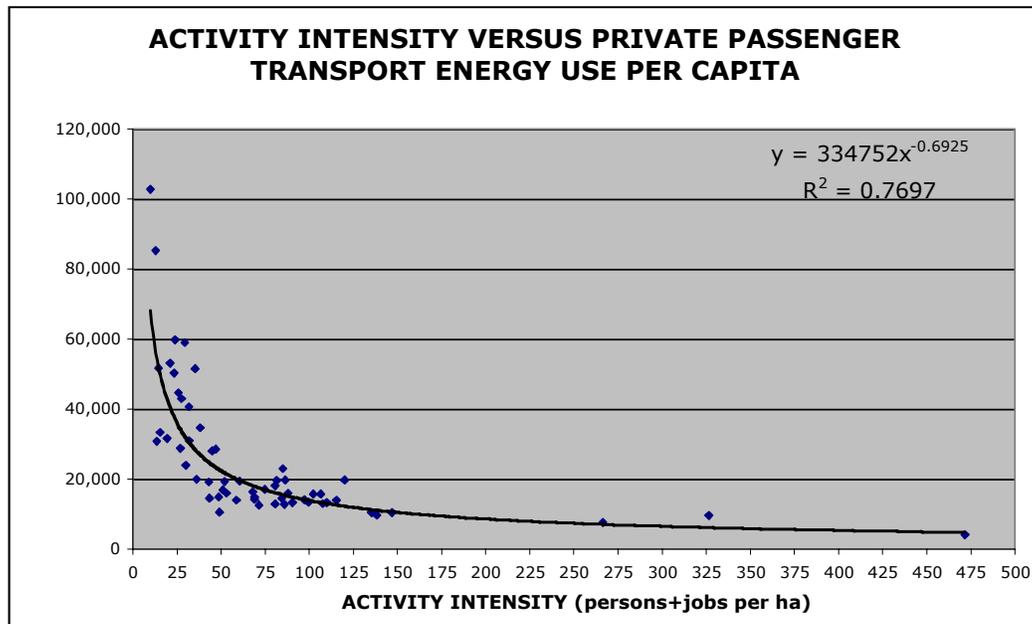
Figure 5. Activity intensity versus private passenger transport energy use in 58 higher income cities, 1995

PER CAPITA PASSENGER TRANSPORT ENERGY USE VERSUS ACTIVITY INTENSITY IN SYDNEY LGAs, 1981

$$y = 58290x^{-0.285}$$
$$R^2 = 0.6368$$

ACTIVITY INTENSITY (PERSONS+JOBS PER HA)

Figure 6. Per capita passenger transport energy use versus activity intensity in Sydney Local Government Areas in 1981.

● Town Centre
○ CBD
— Railway
● Local Centre
Diameter = 20 - 30 km or 1 hour wide by transit
Bus or LRT route

Figure 7. A conceptual plan for re-constructing an automobile city based on Sydney.

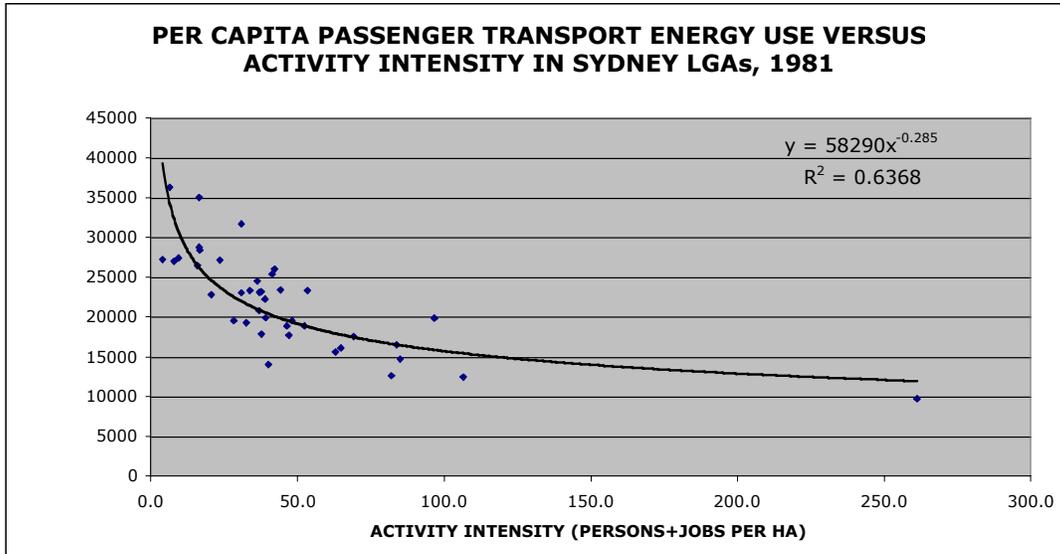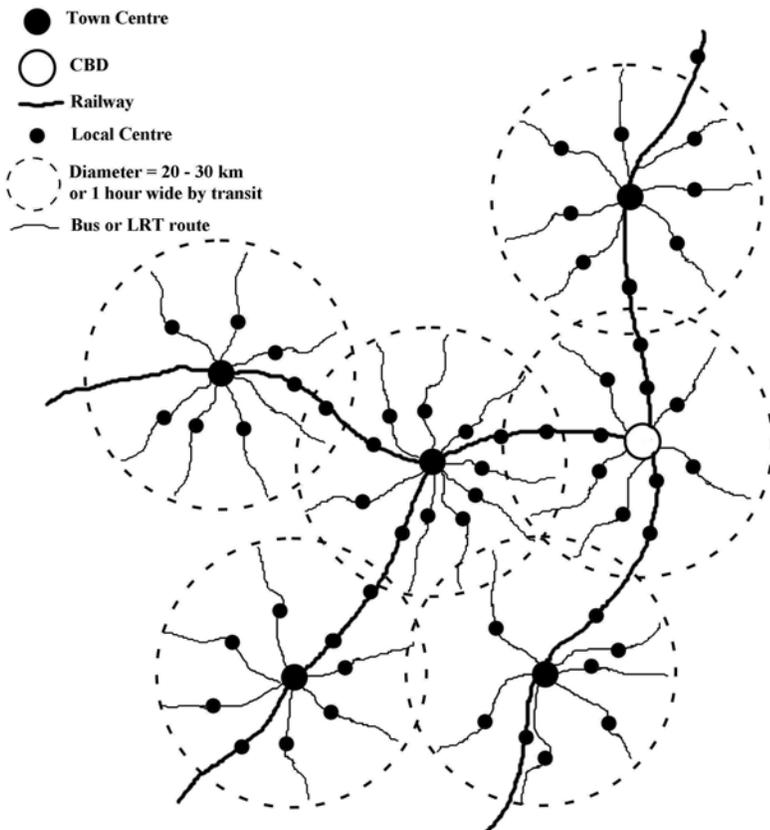| USA	CANADA	AUST/NZ	WESTERN EUROPE	WESTERN EUROPE (continued)	HIGH INCOME ASIA
Atlanta (2.90)	Calgary (0.77)	Brisbane ((1.49)	Graz (0.24)	Athens (3.46)	Osaka (16.83)
Chicago (7.52)	Montreal (3.22)	Melbourne (3.14)	Vienna (1.59)	Milan (2.46)	Sapporo (1.76)
Denver (1.98)	Ottawa (0.97)	Perth (1.24)	Brussels (0.95)	Bologna (0.45)	Tokyo (32.34)
Houston (3.92)	Toronto (4.63)	Sydney (3.74)	Copenhagen (1.74)	Rome (2.65)	Hong Kong (6.31)
Los Angeles (9.08)	Vancouver (1.90)	Wellington (0.37)	Helsinki (0.89)	Amsterdam (0.83)	Singapore (2.99)
New York (19.23)			Lyon (1.15)	Oslo (0.92)	Taipei (5.96)
Phoenix (2.53)			Nantes (0.53)	Barcelona (2.78)	
San Diego (2.63)			Paris (11.00)	Madrid (5.18)	
S. Francisco (3.84)			Marseilles (0.80)	Stockholm (1.73)	
Washington (3.74)			Berlin (3.47)	Bern (0.30)	
			Frankfurt (0.65)	Geneva (0.40)	
			Hamburg (1.70)	Zurich (0.79)	
			Dusseldorf (0.57)	London (7.01)	
			Munich (1.32)	Manchester (2.58)	
			Ruhr (7.36)	Newcastle (1.13)	
			Stuttgart (0.59)	Glasgow (2.18)	
Av. Pop. 5.74	Av. Pop. 2.30	Av. Pop. 2.00	continued	Av. Pop. 2.17	Av. Pop. 11.03

EASTERN EUROPE	MIDDLE EAST	AFRICA	LATIN AMERICA	LOW INCOME ASIA	CHINA
Prague (1.21)	Tel Aviv (2.46)	Dakar (1.94)	Curitiba (2.43)	Manila (9.45)	Beijing (8.16)
Budapest (1.91)	Teheran (6.80)	Cape Town (2.90)	S. Paulo (15.56)	Bangkok (6.68)	Shanghai (9.57)
Krakow (0.74)	Riyadh (3.12)	Jo'burg (2.25)	Bogota (5.57)	Mumbai (17.07)	Guangzhou (3.85)
	Cairo (13.14)	Harare (1.43)		Chennai (6.08)	
	Tunis (1.87)			K. Lumpur (3.77)	
				Jakarta (9.16)	
				Seoul (20.58)	
				HCM City (4.81)	
Av. Pop. 1.29	Av. Pop. 5.48	Av. Pop. 2.13	Av. Pop. 7.85	Av. Pop. 9.70	Av. Pop. 7.19

Table 1. Eighty-Four Completed Cities in the Millennium Cities Database for Sustainable Transport by Region.

Note: Population sizes are shown next to each city in millions with the average population size per city for the group shown at the bottom of each column.

The abbreviations for the city groupings used in Table 1 are as follows.

HIGHER INCOME
USA   US cities
ANZ   Australia/New Zealand cities
CAN   Canadian cities
WEU   Western European cities
HIA   High income Asian

LOWER INCOME
EEU   Eastern European cities
MEA   Middle Eastern cities
LAM   Latin American cities
AFR   African cities

LIA   Low income Asian cities
CHN   Chinese cities

VARIABLE	UNITS	USA	ANZ	CAN	WEU	HIA
Passenger car passenger kilometres per capita	p.km/person	18,155	11,387	8,645	6,202	3,614
Motor cycle passenger kilometres per capita	p.km/person	45	81	21	119	357
Total private passenger kilometres per $ of GDP	p.km/$1000	579.86	579.91	416.14	197.05	125.76
Proportion of daily trips by non motorised modes	%	8.1%	15.8%	10.4%	31.3%	28.5%
Proportion of daily trips by motorised public modes	%	3.4%	5.1%	9.1%	19.0%	29.9%
Proportion of daily trips by motorised private modes	%	88.5%	79.1%	80.5%	49.7%	41.6%
Urban density	persons/ha	14.9	15.0	26.2	54.9	150.3
Metropolitan gross domestic product per capita	USD	$31,386	$19,775	$20,825	$32,077	$31,579
Length of freeway per person	m/ person	0.156	0.129	0.122	0.082	0.020
Length of freeway per $ of GDP	km/$1000	4.97	6.52	5.85	2.56	0.65
Total length of reserved public transport routes per 1000 persons	m/1000 person	48.6	215.5	55.4	192.0	53.3
Parking spaces per 1000 CBD jobs		555	505	390	261	105
Average road network speed	km/h	49.3	44.2	44.5	32.9	28.9
Overall average speed of public transport	km/h	27.4	32.7	25.1	25.7	29.9
* Average speed of buses	km/h	21.7	23.3	22.0	20.2	16.2
* Average speed of metro	km/h	37.0		34.4	30.6	36.6
* Average speed of suburban rail	km/h	54.9	45.4	49.5	49.5	47.1
Ratio of public versus private transport speeds		0.58	0.75	0.57	0.79	1.04

Table 2. Land use, transport infrastructure and transport system characteristics in higher income regions, 1995.

VARIABLE	UNITS	EEU	MEA	LAM	AFR	LIA	CHN
Passenger car passenger kilometres per capita	p.km/person	2,907	3,262	2,862	2,652	1,855	814
Motor cycle passenger kilometres per capita	p.km/person	19	129	104	57	684	289
Total private passenger kilometres per $ of GDP	p.km/$1000	491.70	618.94	601.53	960.57	676.33	466.39
Proportion of daily trips by non motorised modes	%	26.2%	26.6%	30.7%	41.4%	32.4%	65.0%
Proportion of daily trips by motorised public modes	%	47.0%	17.6%	33.9%	26.3%	31.8%	19.0%
Proportion of daily trips by motorised private modes	%	26.8%	55.9%	35.4%	32.3%	35.9%	15.9%
Urban density	persons/ha	52.9	118.8	74.7	59.9	204.1	146.2
Metropolitan gross domestic product per capita	USD	$5,951	$5,479	$4,931	$2,820	$3,753	$2,366
Length of freeway per person	m/ person	0.031	0.053	0.003	0.018	0.015	0.003
Length of freeway per $ of GDP	km/$1000	5.26	9.59	0.62	6.41	3.99	1.17
Total length of reserved public transport routes per 1000 persons	m/1000 person	200.8	16.1	19.3	40.2	16.1	2.3
Parking spaces per 1000 CBD jobs		75	532	90	252	127	17
Average road network speed	km/h	30.8	32.1	31.5	39.3	21.9	18.7
Overall average speed of public transport	km/h	21.4	20.9	18.4	31.4	18.0	13.6
* Average speed of buses	km/h	19.3	18.5	17.8	25.8	16.2	12.5
* Average speed of metro	km/h	29.5	-	32.4	-	33.9	35.4
* Average speed of suburban rail	km/h	37.6	36.6	41.0	34.4	33.0	-
Ratio of public versus private transport speeds		0.71	0.68	0.60	0.80	0.81	0.73

Table 3. Land use, transport infrastructure and transport system characteristics in lower income regions, 1995.

Overall Transport Energy Indicators	UNITS	USA	ANZ	CAN	WEU	HIA
Private passenger transport energy use per capita	MJ/person	60,034	29,610	32,519	15,675	9,556
Private passenger transport energy use per $ of GDP	MJ/$1000	1913	1497	1562	489	303
Public transport energy use per capita	MJ/person	809	795	1,044	1,118	1,423
Public transport energy use per $ of GDP	MJ/$1000	26	40	50	35	45
Energy use per private passenger vehicle kilometre	MJ/km	4.6	3.9	5.0	3.3	3.3
Energy use per public passenger vehicle kilometre	MJ/km	26.3	14.9	22.0	14.7	14.4
Energy use per private passenger kilometre	MJ/p.km	3.25	2.56	3.79	2.49	2.33
Energy use per public transport passenger kilometre	MJ/p.km	2.13	0.92	1.14	0.83	0.48
Overall energy use per passenger kilometre	MJ/p.km	3.20	2.43	3.52	2.17	1.40
Public Transport Energy Use per Vehicle Kilometre by Mode						
Energy use per bus vehicle kilometre	MJ/km	28.8	17.0	24.1	16.3	17.3
Energy use per tram wagon kilometre	MJ/km	19.1	10.1	12.1	13.7	7.9
Energy use per light rail wagon kilometre	MJ/km	17.1	-	13.1	19.5	11.7
Energy use per metro wagon kilometre	MJ/km	25.3	-	10.6	11.6	10.0
Energy use per suburban rail wagon kilometre	MJ/km	49.9	12.1	48.8	15.4	10.4
Energy use per ferry vessel kilometre	MJ/km	846.5	170.5	290.8	120.7	601.7
Public Transport Energy Use per Passenger Kilometre by Mode						
Energy use per bus passenger kilometre	MJ/p.km	2.85	1.66	1.50	1.17	0.84
Energy use per tram passenger kilometre	MJ/p.km	0.99	0.36	0.31	0.72	0.36
Energy use per light rail passenger kilometre	MJ/p.km	0.67	-	0.25	0.69	0.34
Energy use per metro passenger kilometre	MJ/p.km	1.65	-	0.49	0.48	0.19
Energy use per suburban rail passenger kilometre	MJ/p.km	1.39	0.53	1.31	0.96	0.24
Energy use per ferry passenger kilometre	MJ/p.km	5.41	2.49	3.62	5.66	3.64

Table 4. Transport energy use and efficiency in higher income regions, 1995.

Note: In this table and Table 5, the energy use of electrically powered modes is based on end use or actual delivered operating energy. The primary energy use for electric rail modes in each city will vary according to the overall efficiency of electrical generation in each country, including power station efficiencies and transmission losses. The use of primary energy in modal energy consumption for electrical modes would have necessitated a fuller accounting of the energy used in producing and delivering petrol, diesel and gaseous fuels, if a genuine comparison were to be made.

Transport Energy Indicators	UNITS	EEU	MEA	LAM	AFR	LIA	CHN
Private passenger transport energy use per capita	MJ/person	6,661	10,573	7,283	6,184	5,523	2,498
Private passenger transport energy use per $ of GDP	MJ/$1000	1,119	1,930	1,477	2,193	1,471	1,055
Public transport energy use per capita	MJ/person	1,242	599	2,158	1,522	1,112	419
Public transport energy use per $ of GDP	MJ/$1000	209	109	438	540	296	177
Energy use per private passenger vehicle kilometre	MJ/km	3.1	4.2	3.7	3.7	2.6	2.7
Energy use per public passenger vehicle kilometre	MJ/km	11.8	16.1	16.9	9.5	11.9	10.6
Energy use per private passenger kilometre	MJ/p.km	2.35	2.56	2.27	1.86	1.78	1.69
Energy use per public transport passenger kilometre	MJ/p.km	0.40	0.67	0.76	0.51	0.64	0.28
Overall energy use per passenger kilometre	MJ/p.km	1.31	1.99	1.60	1.26	1.20	0.87
Public Transport Energy Use per Vehicle Kilometre by Mode							
Energy use per bus vehicle kilometre	MJ/km	14.2	20.6	18.0	18.1	14.4	9.8
Energy use per tram wagon kilometre	MJ/km	10.5	2.9	-	-	-	-
Energy use per light rail wagon kilometre	MJ/km	19.7	14.3	-	-	11.7	-
Energy use per metro wagon kilometre	MJ/km	10.4	-	12.7	-	21.3	10.5
Energy use per suburban rail wagon kilometre	MJ/km	5.2	35.8	4.7	17.5	14.7	-
Energy use per ferry vessel kilometre	MJ/km	84.2	54.0	-	-	25.0	297.6
Public Transport Energy Use per Passenger Kilometre by Mode							
Energy use per bus passenger kilometre	MJ/p.km	0.56	0.74	0.75	0.57	0.66	0.26
Energy use per tram passenger kilometre	MJ/p.km	0.74	0.13	-	-	-	-
Energy use per light rail passenger kilometre	MJ/p.km	1.71	0.20	-	-	0.05	-
Energy use per metro passenger kilometre	MJ/p.km	0.21	-	0.19	-	0.46	0.05
Energy use per suburban rail passenger kilometre	MJ/p.km	0.18	0.56	0.15	0.49	0.25	-
Energy use per ferry passenger kilometre	MJ/p.km	4.87	2.32	-	-	2.34	4.90

Table 5. Transport energy use and efficiency in lower income regions, 1995.