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Environmental and resource constraints on Asian urban travel

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Abstract: In industrialising countries, personal income has been the main constraint on widespread car ownership. However, incomes are rising rapidly in many Asian cities, so that traffic congestion and air pollution are replacing income as barriers to higher car ownership. Global oil depletion and climate change are potential additional constraints. The main finding of this paper is that private car travel is unlikely to ever be the dominant mode in Asia's large cities. Instead, a combination of public transport and non-motorised travel seems the only feasible means of sustainably meeting the growing transport needs of congested Asian cities.

Keywords: alternative fuels; alternative propulsion systems; global climate change; local air pollution; oil depletion; urban density; urban heat island; public transport; non-motorised travel.

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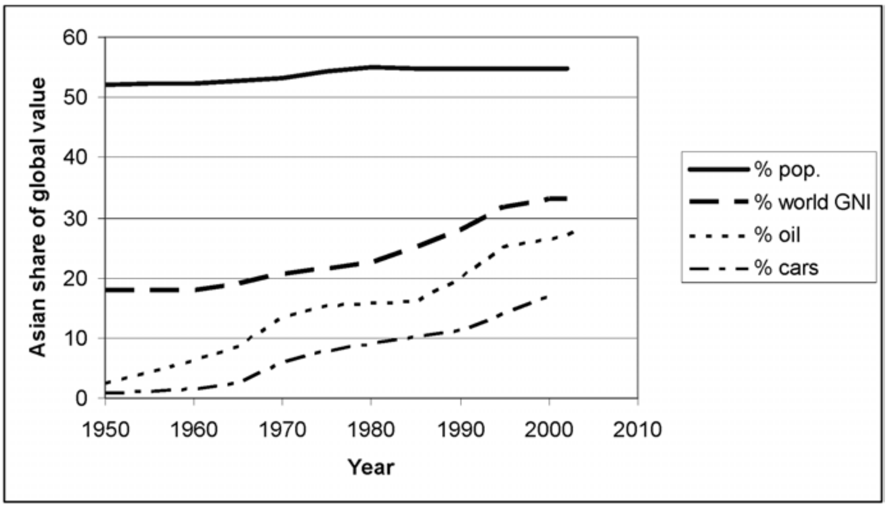
1 Introduction

In the year 1700, China, India, and Japan together accounted for 50% of the world's estimated Gross Domestic Product (GDP) using purchasing power parity exchange rates, not much below their population share (53.5%). GDP per capita was similar in all three countries. However, by 1978, GDP per capita in both India and China had fallen to around 5% of that of the USA (Maddison, 1998). Since then, China, then India, following Japan's earlier lead, have experienced strong economic growth. Today, China, Japan and India are respectively the world's second, third and fourth largest economies (World Bank, 2004).

In this paper, Asia will be defined as including Pakistan and China, all Asian countries to the east and south of these two, plus Mongolia. So defined, Asia's population in 2002 numbered 3.40 billion out of a world total of 6.20 billion, or nearly 55%. This proportion of the world population has risen little from its 1950 value of 52% (United Nations, 2004). Figure 1 shows how Asia has increased its share of world oil, world gross 'national' income (world GNI), and cars since 1950. However, even with the rapid growth in recent years, in 2000 car ownership was only about 104 million, or 17% of the world total, and over 60% of these were in Japan, where car ownership at around 500 per 1000 population now equals that for low-density Australia (World Bank, 2004). Similarly, oil consumption is low compared with its share of world population, let alone compared with Australia or the USA. Asia's share of rail travel, on the other hand, is now close to its population share (World Bank, 2001; United Nations, 2003; Schafer and Victor, 2000).

Figure 1 Asian share of the world's population, GNI, oil consumption, and car ownership, 1950–2000



Source: Maddison (1998), World Bank (2001, 2004), United Nations (2003, 2004) and Schafer and Victor (2000)

If present trends continue, Asia's share of world GNI will soon reach – and even surpass – its 55% share of world population, and will continue to overtake the Western countries. What is open to question is whether Asia – particularly urban Asia, which is expected to account for nearly all of Asia's future population growth – can copy the present high car-ownership lifestyles of the West, or even Japan. (Another important question, not discussed here, is whether the car-oriented transport systems of western countries can continue for much longer.) Not only are the cities of industrialising Asia increasing their share of total national population (United Nations, 2004), but urban incomes are usually much higher than in rural areas. The result is that most growth in car ownership is expected to occur in cities (Moriarty, 2000; Kobos et al., 2003).

Asian cities, especially in industrialising Asia, must meet their rising demand for higher levels of mobility without further compromising urban health or levels of access for poorer residents. Urban transport systems, in Asia as elsewhere, must also in future minimise both their trace gas emissions (if serious global climate change is to be averted), and oil consumption. They must also not further worsen the already serious traffic congestion and regional air pollution problems (Sperling and Classen, 2002). This paper examines whether it is possible in future for Asia's growing cities to have car-based transport systems, by first examining the nature and severity of these constraints, then the possible solutions. The main finding is that private car travel is unlikely to be the future dominant mode in Asia's large cities, even if that is presently the case for many Japanese cities. Instead, a combination of public transport and non-motorised travel seems the only feasible means of meeting the growing transport needs of Asian cities in a sustainable manner.

2 Potential constraints on future travel in Asian cities

Future travel growth in Asian cities will face several serious obstacles, some of which are evident today. Congestion, as reflected in low road traffic speeds, is already serious in many Asian cities, even those with car ownership levels low by western standards. Low quality fuels, low emission standards, and traffic congestion increasingly contribute to the very high pollution levels found in the cities of industrialising Asia. Transport emissions also have impacts at the regional and global level. Global oil depletion is a challenge to road transport everywhere. Further, these problems can only intensify if vehicle ownership rises to anywhere near projected levels. The following sub-sections examine in turn the land constraint, vehicle emissions, and future petroleum availability issues.

2.1 Urban congestion

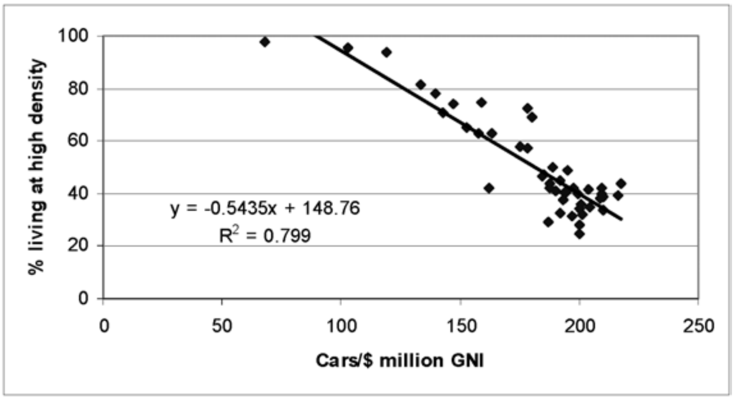
Already, large Asian cities typically have urban densities an order of magnitude larger than large US or Australian cities (Moriarty, 2000; Census and Statistics Department, 2004; Statistics Bureau, 2004). In a 1990 study of transport in 46 of the world's largest cities, the average urban density of the six Australian cities was 1220/km^2, and for 13 US cities, 1420/km^2, but for nine Asian cities, 16,190/km^2 (Newman and Kenworthy, 1999). In 2003, Kowloon's population density was 43,030/km^2 (Census and Statistics Department, 2004). As a result, traffic congestion levels, as measured for example by average vehicle speeds, are already severe in Asian cities (Newman and Kenworthy, 1999).

Further, in industrialising Asia, where urbanisation is typically low, urban populations are expected to continue their rapid growth of recent years. Thus the UN project China's urban population to grow from 504 to 878 million in 2030, and India's from 301 to 586 million. Overall, the UN expect Asia to increase its share of urban residents from 36.7% in 2003 to 51.8% in 2030 – an extra 1024 million people to be accomodated in Asian cities (United Nations, 2004). Given both this huge increase in urban populations, and the need to conserve agricultural land in Asian countries, it is unlikely that even rising prosperity can hope to reduce urban population densities much.

When considering the future of urban areas and their transport in industrialising Asian countries, it is useful to look at the experience of Asian countries that have already achieved high standards of living, particularly Japan, Singapore and Hong Kong. Figure 2 shows the share of prefectural population living at high densities for all Japanese prefectures (except for isolated Okinawa) plotted against car ownership

(Statistics Bureau, 2004). Car ownership figures have been normalised by prefectural incomes per capita, with the all-Japanese average set at Japan's 2000 GNI per capita of $27,080 (in 2000 $US, using purchase power parity exchange rates) (World Bank, 2004). It is clear from the high correlation coefficient ($R^2 = 0.799$) that car ownership – and presumably car travel – in Japan is heavily influenced by population density.

Figure 2 Cars/$m GNI vs. % living at high density, Japan prefectures, 2000



Source: Statistics Bureau (2004)

Table 1 confirms that this dependency is more general by giving data for Tokyo, Singapore, Hong Kong, together with Melbourne, four cities in different countries with similar living standards in 1990. Density affects road – and parking – space per person, and thus average car travel speeds. Relative door-to-door speeds for car and public transport, particularly rail, in turn influence car ownership and car's share of urban vehicular travel. Other explanatory factors besides urban congestion – such as good public transport provision (as in Tokyo) and restrictions on vehicle ownership (as in Singapore) – will also be important, but to some extent these policies are the *result* of congestion.

Table 1 Population and travel-related characteristics of four cities, 1990

City	*Population* (*millions*)	*Density* (*persons*/*km*^{2})	*Cars/1000 population*	*Car pass-km*/*capita*	*Car's share* (%)	*Road space* (*m*/*person*)
Hong Kong	5.80	30050	35	815	17.7	0.3
Singapore	3.02	8680	90	3170	53.3	1.1
Tokyo (four prefectures)	31.80	7100	260	3175	36.6	3.9
Melbourne	3.13	1490	480	9780	92.0	7.7

Source: World Bank (2004) and Newman and Kenworthy (1999)

Not all Asian cities presently suffer from congestion sufficient to drastically curtail car use. Nor will they necessarily in the future; smaller cities and even some lower density larger ones will be able to accommodate at least European levels of car use. Even in densely populated Japan, the position is very different for different large cities. Nagoya, the third largest metropolis, has nearly 70% of all vehicular trips by car

(Table 2). And in Tokyo, the largest, the situation is very different for the inner and outer areas. In the densely populated *ku* area of Tokyo, the car's share of vehicular trips has not risen in 30 years. Indeed, the total number of vehicular passenger trips was the same in 2000 as in 1990. (The 1990s recession, while it doubtless slowed down surface travel growth throughout Japan, can not be the main explanation. While Tokyo prefecture did see its share of Japan's GNI fall between 1990 and 1995, its share rose between 1995 and 2000. Yet the *ku* area experienced a slight increase in total trips 1990–1995, but a fall 1995–2000) (Statistics Bureau, 2004). For the rest of Tokyo metropolis, and Osaka overall, both total trips and car's share continue to grow slowly, just as for Japan overall. The share of trips by car in each of the three metropolitan areas corresponds closely with their car ownership levels (Statistics Bureau, 2004).

Table 2 Car's share of vehicular trips (%) in Japan's three largest cities, 1970–2000

City/area	*1970*	*1980*	*1990*	*2000*
Tokyo (50 km radius)	17.5	23.3	30.5	33.9
ku area	*18.3*	*15.5*	*17.5*	*17.3*
Rest of Tokyo	*16.1*	*33.7*	*45.7*	*51.5*
Osaka (50 km radius)	17.0	28.7	35.7	41.7
Nagoya (40 km radius)	32.0	55.3	64.2	68.6

Source: Statistics Bureau (2004)

In summary, evaluating the prospects for high levels of car use in the large cities of industrialising Asia requires a close look at Asia's existing high-income cities. Their experience shows that once personal incomes are no longer the barrier to high car ownership, urban density becomes the crucial variable. If – as is likely, given the extra billion urban residents projected for 2030 – most of the future urbanisation in industrialising Asia occurs at high densities, the prospects for accomodating car-based urban transport systems look poor.

2.2 Urban air pollution emissions: local, regional, global

Urban transport, freight and passenger, impacts on the urban atmospheric environment in several ways. It has long been known that urban air pollution in general can have adverse effects, not only on human health (particularly on the incidence of respiratory diseases), but also on nearby crops and forests, as well as on the durability of building materials (Molina and Molina, 2004). It also affects visibility. Large Asian cities are among the world's most polluted, and increasingly, this air pollution is transport-related (Kobos et al., 2003; Molina and Molina, 2004; Ramanathan and Parikh, 1999; Harrington and McConnell, 2003), a trend that can can only strengthen if urban vehicle numbers and road transport grow as predicted. What is new is the realisation that air pollution has regional and even global effects. Pollutants with atmospheric lifetimes greater than a week or so can be transferred to other continents. Hence East Asian dust and trace gases are carried to North America, while ozone from Europe is carried to Asia (Akimoto, 2003). On a more regional scale, China's air pollution is of concern to Japan and South Korea. Finally, any decrease in hydroxyl concentration in the atmosphere would increase the lifetimes of key pollutants, and could "turn smog from a moderately serious local or regional issue into a life-threatening global problem" (Harrington and McConnell, 2003).

Over the past two decades, the issue of global climate change has created extraordinary interest – and some controversy. Emissions of heat-trapping gases into the atmosphere, particularly CO_2, from fossil fuel combustion and land-use changes, cause global warming by altering the Earth's radiation balance (Intergovernmental Panel on Climate Change, 2001). The debate is usually framed as being mainly a future problem, and one which at least at present only concerns the industrialised countries, including Japan. Thus the Kyoto Protocol only requires these nations to reduce their carbon emissions. Further, the complex global general circulation models used for climate prediction necessarily have poor grid resolution, resulting in their forecasts for regional or even national climate change being acknowledged as unreliable policy guides at present (Intergovernmental Panel on Climate Change, 2001).

Recently, there has been some support for 'Plan B', a proposal backed by the UN Environment Program and the British government, among others. This plan advocates that by the year 2050, all nations converge on a uniform figure of 1.1 tonnes CO_2 per capita, in order to avert serious climatic change (Pearce, 2003). Japan, Singapore and Korea (9.3, 9.1 and 14.7 tonnes respectively) already have per capita emissions many times this limit, but even China's 2.2 tonnes is twice this value, while India has just reached 1.1 tonnes/capita (World Bank, 2004). If Plan B is adopted, it will not be possible for Asia – or other regions – to support high levels of private transport in its present form. Recent research suggests that climate sensitivity – the global temperature increase that will result from a doubling of CO_2 equivalent in the atmosphere – may be much higher than previously thought (Pearce, 2005; Stainforth et al., 2005). Indeed, dangerous climatic change may already be occurring (Stott et al., 2004). If so, Plan B, or more likely a similar policy, will need to be implemented even earlier.

A newly described and studied phenomenon is the 'atmospheric brown cloud', which has been observed in North America, South America, and Europe as well as Asia (Ramanathan and Crutzen, 2003). Ramanathan and Crutzen (2003) estimate that for South Asia during the dry season, the regional radiative forcing by anthropogenic releases of aerosols is an order of magnitude greater than that for greenhouse gases. The net affect is a local cooling. Greenhouse gas (GHG) releases are still important, since they have global as well as regional effects, mainly because their atmospheric lifetimes are a century or more rather than a week or so for aerosols. These aerosols can also have a large impact on the regional hydrological cycle, including the moonsoonal circulation. Their important conclusion is that "air pollution and climate changes are intricately linked and should be addressed under one common framework".

The interactions between the various atmospheric pollutants, and their often different short and long term effects, make it very difficult to devise effective policies for air pollution amelioration. Trade-offs are sometimes necessary. For example, since nitrogen oxides (NO_x) are an essential ingredient in urban smog, their reduction is desirable for health reasons. And in the short term, reducing NO_x also mitigates global warming, by reducing tropospheric ozone. But over the longer term (a decade or so), NO_x reductions will lead to increases in both ozone and methane, resulting in net warming. However, if CO emissions are reduced along with NO_x – as is often the case – both short and long term warming are reduced (Anon, 2001).

Finally, urban heat island (UHI) effects have been found in large Asian cities, as well as elsewhere (Molina and Molina, 2004; Crutzen, 2004; Ichinose et al., 1999; Westrup, 2004). The UHI effect is caused by high anthropogenic heat releases per unit area in the centre of cities, combined with albedo changes as original vegetation gives way to concrete and asphalt. In wintertime in central Tokyo, for example, the average anthropogenic heat flux (in W/m^2) is higher than solar radiation (Ichinose et al., 1999). The result is that city temperatures can average several degrees C warmer than the surrounding areas. The additional heat exacerbates smog formation from NO_x and volatile organic compounds (VOCs), and can even increase rainfall downwind from the city (Westrup, 2004). UHIs can only increase in intensity as Asian cities grow and energy consumption likewise increases. Like 'atmospheric brown clouds', the UHI effect adds to the complexity of understanding the urban atmosphere, and probably, also to the severity of urban air pollution.

In summary, the combustion of fuels, whether for transport, industry or domestic purposes, can have impacts that range from strongly localised, such as raised inner city temperatures, to health and climate effects at all scales from the local to the global. The effects can also be long-term, as with greenhouse gas emissions, or short-term, as in air pollution episodes. Different pollutants can produce complex reactions in the atmosphere, often making it difficult to devise policies for abatement, as tradeoffs may be necessary. The Asian Development Bank has recently started a 'Clean Air Initiative' for Asia. Yet if population, incomes, industry, and car ownership grow as predicted in industrialising Asian cities it will prove very difficult achieve desired air quality standards.

2.3 Global and Asian oil depletion

The *BP 2004 Statistical Review of World Energy* (BP, 2004) gives published 'proved' world oil reserves – including non-conventional oil, gas condensate, and natural gas liquids (NGL) – at the end of 2003 as 1148 billion barrels, which also includes some provision for Canadian tar sands 'under active development'. This figure compares with world oil consumption in 2003 of 28.5 billion barrels (BP, 2004). More important than total reserves is the amount of oil that can be extracted annually. For petroleum, problems begin not when all, or even most, oil is depleted, but when production cannot meet potential demand. It is the capacity of the 'pipe', not the 'tank', that matters. World oil consumption in late 2004 was about 82 million barrels per day (mbd), and rising. The US Energy Information Administration (EIA) expects world oil use to grow to 118 mbd by 2025, while the International Energy Agency (IEA) projects 121 mbd for 2030 (Energy Information Administration, 2004; International Energy Agency, 2004). In total contrast, the Association for the Study of Peak Oil and Gas (ASPO) forecasts production to remain at around 80 mbd to 2010, but then fall to 65 mbd in 2020, and 32 mbd by 2050 (Association for the Study of Peak Oil and Gas, 2005).

Why this huge difference in forecasts? The EIA figure is really a demand-based forecast – it assumes that known and new fields of conventional oil, along with increasing amounts of non-conventional oil, can meet demand. And 118 mbd is not a high demand by OECD standards of oil consumption. If, in 2025, all the world's projected population of 7.85 billion (United Nations, 2004) consumed oil at the Australian and Japanese rate of 15.5 bbl/year, total world oil use would be 333 mbd, or four times current usage! The EIA, in effect, tacitly assumes that present global inequities in access to oil will continue. Their optimistic supply analysis is based on the latest assessment of world oil by the US Geological Survey (USGS). ASPO, in contrast, claims that the supply of oil is facing natural limits, and that newly developed fields will not be able to compensate for declining output from existing large fields.

This controversy is, of course, crucially important for the future of transport, both in Asia and elsewhere. Asian oil reserves are very modest, and in fact have fallen from their peak in the early 1990s (BP, 2004). Asia, with 55% of the world's people, had in 2003 only 3.4% of global reserves. Production has levelled off, while consumption is rising rapidly, particularly in industrialising Asia (Table 3). Rising Asian demand, particularly in China, is a driving force in world oil markets today. The IEA predicts that China's oil needs will grow annually by 3.4% out to 2030 (International Energy Agency, 2004). But its 2003 oil consumption was over 11% greater than 2002 (BP, 2004).

Table 3 Oil reserves, production, and consumption, Asia, 1970–2003

	1970	*1980*	*1990*	*2000*	*2003*
Proven reserves (billion bbl)	32.8*	37.1	42.4	40.7	42.9
Production (mbd)	1.81	4.49	5.98	7.11	7.19
Consumption (mbd)	6.13	9.24	12.88	19.97	21.61
China	*0.56*	*1.77*	*2.30*	*4.99*	*5.98*
Japan	*4.00*	*4.94*	*5.30*	*5.58*	*5.45*
India	*0.44*	*0.67*	*1.17*	*2.07*	*2.43*

*Estimate.

Source: United Nations (2003) and BP (2004)

Only the passage of time will tell us whether the EIA/IEA or the ASPO projections of future oil availability are correct. But there are some signs that the lower availability estimate might be closer to reality. First, it is widely acknowledged that global oil reserve estimates are unreliable. Second, the World Energy Commission now accepts that a decline in world oil production will occur soon. Third, even some of the oil majors today acknowledge that current production is several times larger than actual annual oil discoveries (International Energy Agency, 2004; Association for the Study of Peak Oil and Gas, 2005; Laherrere, 2004). Discovery rates are very important: oil cannot be produced until the fields have been found and developed. In fact annual oil discovery vs. year in a region such as the lower 48 US rises to a peak and then declines, with production following a similar curve some decades later. Future oil discoveries can lessen the steepness of oil supply decline, but they cannot much delay the peak in world oil production (Bentley, 2002).

Furthermore, actual new discoveries of oil in recent years are much more in line with the ASPO analysis than that based on the USGS. Given the unreliability of world reserve estimates, the more consistent US data will be used as an illustration. The USGS in their 2000 report predicted that US discoveries of oil, condensate and NGL over the next 30 years from 1st January 1996 would have a mean value of 159 billion barrels (Petzet, 2000). Yet over the nine years to the end of 2004, discoveries added to reserves totalled only about 26 billion barrels (BP, 2004), rather than the 48 billion barrels expected, if, conservatively, annual additions were constant over the entire 30-year period.

If only 65 mbd are available for the world in 2020, and much less in later decades, Asian plans for high car ownership are in trouble – as indeed are the prospects for car-based transport systems everywhere – unless vehicle efficiency can be dramatically increased, or alternatives to oil found and developed soon. The next two sections examine the prospects for reducing transport oil consumption, and with it air pollution, from the local to the global scale, in an urban Asian context.

3 Solutions: improving private transport's primary energy efficiency

Researchers have put much effort into reducing the energy consumption of passenger travel, as emissions are generally also thereby reduced. Three approaches are possible: raising seat occupancy, reducing vehicle mass for a given passenger capacity, and reducing energy use per seat-km. Each approach is discussed below. Vehicle efficiency improvements are especially relevant to the cities of industrialising Asia, given that fuel economy there lags behind that for Japan or Europe (Kobos et al., 2003).

3.1 Improving seat occupancy

Private car occupancy rates vary within fairly narrow limits throughout the world. The effective upper and lower limits for a 5-seat car are 20% (driver only) and 100% respectively, but actual overall occupancies seem to vary only from about 30–50%, when light vehicles for hire are excluded. In high-income countries, including Japan, it has not been possible to raise car occupancy rates in the context of continued increases in car ownership, and declining household size. Australian car occupancy rates, for example, have fallen from over 2.0 in 1960 to about 1.5 today, as average household size fell from 3.5 to 2.6 (Australian Bureau of Statistics, 2004). In Japan, the picture is clouded by the presence of a large share of small *kei* cars, but occupancy rates there have fallen from 1.57 in 1990, when *kei* cars were first officially included, to 1.43 in 2001 (Statistics Bureau, 2004).

Programs to encourage car pooling in western countries have usually met with little success. Motorists there seem resistant to sharing their vehicle with non-family members – understandably, since people have different tastes in music or radio station, in their degree of driving caution, and in standards of punctuality. All these differences dampen enthusiasm for car-pooling, at least when car ownership is high and car travel costs low. Car pooling can also interfere with attempts to combine trips, an important alternative means of reducing car travel.

3.2 Reducing vehicular mass

Popular Japanese car models vary widely in kerb mass, but 750–1500 kg is typical for a 5-seat car, lighter than European or US vehicles. Mass per seat is thus usually in the range 150–300 kg (Plotkin, 2001). The figure is about the same for *kei* cars, where seating capacity as well as mass is reduced. However, there are 5-seat compact cars made in Asia and Europe that have a kerb mass of 125 kg per seat.

Some researchers claim large mass reductions are possible for cars. In the USA, the Rocky Mountains Institute (Lovins and Cramer, 2004) has designed the Hypercar Inc. concept vehicle, *Revolution*. This vehicle represents a radical departure from conventional design, and aims to maximise fuel efficiency without compromising performance, comfort, or safety. This "sporty five-passenger SUV crossover vehicle" (Lovins and Cramer, 2004) has a kerb mass only 47.6% of the equivalent conventional vehicle's 1800 kg. However, it is unlikely that the same degree of mass reduction will be possible in conventional vehicles with a kerb mass already as low as the *Revolution*. An early 1990s lightweight concept vehicle, GM's *Ultralite*, weighed 635 kg and seated four – about 160 kg per seat, no better than the best conventional vehicles. The comprehensive Massachusetts Institute of Technology (MIT) study discussed below assumed that a 23.5% reduction from the 1996 Toyota Camry's kerb mass of 1308 kg could be achieved by 2020. However, vehicle purchase costs would increase (Weiss et al., 2000). The conclusion is that some mass reductions per seat are possible, but large reductions are unlikely for cars if anything like present levels of cost, comfort, safety, and performance are to be maintained.

3.3 Improving vehicular 'well to wheel' energy efficiency

One of the most comprehensive recent studies of the efficiency impact of alternative fuels and propulsion systems was done in the USA at MIT (Weiss et al., 2000). The basis of the calculations was a 1996 petrol-fuelled Toyota Camry. This base vehicle was then compared with year 2020 modelled 'baseline' and 'advanced' petrol-fuelled vehicle, as well as with a variety of other advanced 2020 vehicles with new fuels and/or propulsion systems. The first comparison is of the 1996 and 2020 baseline and advanced conventional cars on a 'well to wheel' efficiency basis, which includes not only the onboard fuel consumption but also the energy lost in converting the primary fuel and getting it to the vehicle. For the US city cycle – more relevant to Asian urban traffic than the US combined cycle – the baseline and advanced 2020 vehicles delivered 0.41 and 0.46 km/Megajoule (MJ) respectively, compared with only 0.26 km/MJ for the 1996 car. Some efficiency gains resulted from mass reductions, as already discussed; the rest came from improvements such as reduced rolling and air resistance.

The second useful comparison, as shown in Table 4, examines only various 2020 advanced vehicles. The same mass reduction measures have been applied to all options, but the resulting kerb masses differ slightly because of different battery mass, for example. The table shows the superiority of hybrid vehicles, with diesel hybrids more energy efficient than the others on a well to wheel basis. For battery electric vehicles (EV), fuel cycle energy use dominates because of the high energy losses in thermal power stations. Other recent US analyses of the relative merits of alternative fuels and propulsion systems (Harrington and McConnell, 2003; Lovins and Cramer, 2004; MacLean et al., 2004; Ahluwalia et al., 2004), arrive at broadly similar conclusions, when due allowance is made for different assumptions about power station efficiencies, hydrogen source, vehicle type, and driving cycle used. For all future efficiencies, the authors stress that the results show what is possible (at a price), not what is likely.

Table 4 Vehicle energy use for various fuel and propulsion alternatives in 2020

Energy use (MJ/km)	*Petrol ICEV*	*Diesel ICEV*	*Petrol hybrid*	*Diesel hybrid*	*CNG hybrid*	*HFCV hybrid*	*Battery EV*
Fuel cycle	0.37	0.22	0.26	0.15	0.21	0.70	1.25
Vehicle use	1.79	1.58	1.21	1.03	1.16	0.91	0.58
Total (‘well to wheels’)	2.16	1.80	1.47	1.17	1.37	1.60	1.83
Overall km/MJ	*0.46*	*0.55*	*0.68*	*0.85*	*0.73*	*0.62*	*0.55*

Source: Weiss et al. (2000)

Several evaluations of modelled or likely future efficiency gains in Asia are also available. A study of the potential for reductions in oil use and emissions from China’s overall road transport (He et al., 2004) assumed an 87% improvement in car fuel economy by 2030 in their ‘high efficiency’ scenario. This modelled improvement slowed down projected 2030 transport oil use and CO_2 emissions compared with the base case, but both still rose by about 300%! Similarly, for India, a 1990s study (Ramanathan and Parikh, 1999) assumed an annual 3% vehicle efficiency gain in the ‘emphasis on efficiency improvements’ scenario. Even this 143% improvement over 30 years still gave a 2-fold rise in petrol use in 2020. Actual gains are likely to be much smaller. In Japan, government fuel economy standards for the petrol-fuelled fleet, if achieved, will only lead to an average 23% improvement from 1995 to 2010 (Plotkin, 2001).

The hydrogen for the hydrogen fuel cell vehicle (HFCV) hybrid on the table is assumed derived from natural gas. In Asia, natural gas is increasingly supplied from imported LNG (BP, 2004), with its high fuel cycle energy costs for liquefaction. Efficiency would be much lower than the 0.73 km/MJ given in the Table. If the hydrogen was produced by electrolysis of water, the efficiency would again be lower (Romm, 2004). It is clear that HFCVs make little sense from a primary energy use viewpoint. And there are additional reasons why HFCVs are a poor bet for Asia’s cities. Not only are their costs still very high, but there are problems with noble metal catalyst availability, durability of fuel cells under automotive conditions, on-board hydrogen storage, safety, and fuel availability (Romm, 2004; Moriarty and Kennedy, 2004; Hammerschlag and Mazza, 2004; Northeast Advanced Vehicle Consortium, 2003).

Table 4 also shows the high fuel cycle energy losses for electric-powered transport. At present, Asian fossil fuel power stations often have efficiencies well below that for existing best-practice plants, let alone what is possible. In contrast, the potential for improving oil refinery efficiency is not large, since, as Table 4 shows, only 12–18% of total energy use is consumed in refining and delivering petroleum-based fuels. However, non-conventional oil sources, such as tar sands or oil shales, are expected to play a progressively increasing role in the future, as world reserves of conventional oil dwindle (Energy Information Administration, 2004; International Energy Agency, 2004). Oil from tar sands is already produced in Canada, but the energy requirements for a litre of petrol in a car’s fuel tank are much greater than that from imported crude oil. Greater reliance on such fuels (as well as on enhanced oil recovery, deep water and polar oil, and high-sulphur crudes) will make it progressively more difficult to improve ‘well to tank’ energy conversion efficiency.

To summarise, no improvement in occupancy rates can be expected for urban cars if ownership increases. Mass reductions of perhaps 20–30% appear possible without compromising present car comfort, safety, or performance levels. Overall, even optimistic improvements in conventional vehicles will still lead to greatly increased total petrol consumption in the cities of industrialising Asia. Hybrid vehicles are already gaining market share in Japan, and, particularly if diesel-fuelled, appear to offer the best prospects for further gains in urban vehicle efficiency, measured in well-to wheels km/MJ.

4 Solutions: adopting alternative transport fuels to reduce emissions and oil use

One way for Asian cities to reduce GHG emissions from transport is to move to fossil fuels with a lower carbon/hydrogen ratio than petrol or diesel. Liquefied petroleum gas (LPG) – mainly obtained from natural gas fields – and compressed natural gas (CNG) are often advocated as transport fuels for this reason (Molina and Molina, 2004; Ramanathan and Parikh, 1999). These more homogeneous fuels also reduce air pollution – in Delhi, the entire bus fleet now runs on less-polluting CNG (Bose, 2003). But their GHG emissions per unit of primary energy are at best only marginally better than petrol (Weiss et al., 2000; MacLean et al., 2004). Nor can they offer a long-term solution for oil depletion. Published world reserves of natural gas have only the same energy content as oil's reserves, and gas is needed for non-transport uses, which are rapidly growing worldwide. Asia's share of world natural gas reserves is around 6%, not much higher than its share of oil reserves (BP, 2004).

As already discussed, diesel vehicles have higher km/MJ of primary energy than equivalent petrol ones. For this reason, many analysts also consider diesel as a way of reducing GHG emissions (Harrington and McConnell, 2003; Weiss et al., 2000). However, diesel engines emit fine carbon particles at a far higher rate than petrol engines. Not only are these increasingly recognised as a serious urban health hazard (Molina and Molina, 2004), but recent modelling research shows that fine black carbon can have a variety of impacts, both positive and negative, on global warming (Jones, 2002). The net result, however, is that "1 gram of black carbon is 360,000–840,000 times as powerful a global warming as 1 gram of CO_2" (Jones, 2002). With a 100 year time frame, incorporating all the global climate change effects of diesel show that its global warming impact is greater than that for petrol. Over a 150 year time frame, however, the model predicts that diesel will be more climate friendly. For the foreseeable future, using diesel rather than petrol will save oil, but at the expense of higher local and global air pollution, unless diesel's carbon emissions can be greatly reduced without worsening other emissions.

Moving completely away from fossil fuels seems to offer for many the route to 100% 'green' passenger (and freight) transport. The failure of previously-discussed approaches to reducing transport's primary energy consumption is much less relevant if the energy produced is GHG emissions-free, and not based on petroleum. One such approach is to use biomass fuels in Internal Combustion Engine Vehicles (ICEV), as in Brazil and the USA. Although the addition of ethanol as an oxygenate might be justified in urban areas as a local air pollution reduction measure, biomass liquid fuels cannot significantly reduce Asia's transport GHG emissions or oil use. Controversy exists, particularly in the

USA, as to whether replacing petrol with ethanol reduces equivalent CO_2 emissions (Hodge, 2002). Grain alcohol saves petroleum, but it may not reduce GHGs at all. Given that Asia already imports a significant share of its food, ethanol from food crops, can, at best, only be locally important.

Ethanol from cellulosic materials would reduce GHG emissions, but no conversion plants operate commercially anywhere in the world. Even the potential for cellulosic ethanol – should it ever prove feasible – is limited. Net primary production (NPP) measures the net conversion of atmospheric CO_2 by photosynthesis into plant biomass. A recent study (Imhoff et al., 2004) has shown that the NPP of biomass in Asia, whether produced by nature or human agriculture and forestry, is already heavily utilised by humans – our own species, but still only one of millions. For 'East Asia', humans already appropriate 63% of NPP, while for 'South central Asia' (India and neighbouring countries), the figure rises to over 80%. ('Western Europe' also already uses a high share of NPP – over 70%.) In summary, very little Asian biomass can be diverted to transport fuels, particularly given the expected growth in both population and incomes, and resulting food, fibre, and forest products demand.

We are left with electricity from non-fossil fuel sources. These sources today provide 26.6% of Asian electricity, down from 28.4% in 1980 (World Bank, 2004). If they supplied 100%, both CO_2 emissions and oil use would be near zero for all electricity-based transport. Local air pollution would also be zero, except for hydrogen-fuelled ICEVs, where NO_x emissions would still occur. All hydrogen-fuelled vehicles would still face the daunting problem of adequate and safe on-board H_2 storage (Romm, 2004; Moriarty and Kennedy, 2004; Hammerschlag and Mazza, 2004; Northeast Advanced Vehicle Consortium, 2003).

Hydrogen as a transport fuel faces yet another environmental problem, regardless of propulsion system or primary energy source used. A hydrogen-fuelled transport system inevitably means leaking hydrogen. Like CO, hydrogen is an indirect GHG; it removes OH^- radicals from the atmosphere, and so increases atmospheric methane concentrations (Ananthaswamy, 2003; Schultz et al., 2003). Hydrogen escape could also lead to oxidation of H_2 in the stratosphere, resulting in increased levels of water vapour there, with complex effects on climate (Tromp et al., 2003). The effects are very dependent on estimates of H_2 leakage rates, as well as the primary energy source to produce H_2. The main point is that we presently cannot be certain that replacing petroleum fuels by hydrogen will in practice reduce global climate forcing.

This section and the previous one have examined the potential for reducing – or even eliminating – car travel's emissions impacts, from the local to the global, and petroleum use. Hybrid vehicles offer the best option in an Asian urban traffic context, because of regenerative braking. But in the context of ever-rising urban car numbers, no technical fix appears capable of doing more than slowing the rate of increase in GHGs or oil use.

5 Solutions: public transport and non-motorised travel

Unlike car occupancy rates, public transport occupancy rates tend to rise if overall patronage rises, as has also been true for air travel. But they can also fall if overall patronage declines, as has happened historically with bus transport in Japan. In 1975, buses carried an average of 20.2 passengers, but in 2001 only 12.7 passengers (Statistics Bureau, 2004). Policy initiatives which boost public transport use from low levels will usually also increase vehicle occupancy rates, mainly because much of the increase in patronage can be accommodated on existing services. New services will usually only be introduced when existing services are judged as too crowded. The effective upper and lower limits on seat occupancy rates are 0% and 100% (or even higher if over-crowded). Actual figures also vary more than for car travel, with Asian public transport systems having among the world's highest occupancy rates. In contrast, growth in car ownership has everywhere resulted in declining occupancy rates for cars.

Buses, particularly minibuses, have a mass per passenger space already lower than that for cars, with similar prospects for further mass reductions. Rail vehicles (trams as well as trains), tend to have higher mass/seat ratios – as high as 400–450 kg/seat. One reason for the higher ratio is because seating capacity is often sacrificed for standing room on heavily patronised rail systems – mass per passenger space is much lower. There appears to be large potential for rail mass reduction by using lighter-weight aluminium, higher strength stainless steel, longer carriages – which enable reduction in bogie numbers – or 'double-decker' designs. For older rail carriages, a 50% reduction in mass is readily achieved by moving to present best practice (White, 1995).

Existing public transport in Asia is also far more energy efficient than car travel. The energy efficiency of the 1996 Camry, discussed above, can be compared with that for present Asian urban public transport. In the mid-1990s, Indian bus fuel efficiency was 4.8 pass-km/MJ, and for rail diesel, 4.2 pass-km/MJ (Ramanathan and Parikh, 1999). With 1.5 occupants, the Camry delivers only 0.46 pass-km/MJ (Weiss et al., 2000), giving a 10-fold difference. Bose (2003) reports a lower figure for India: a five-fold difference for a 52-seater bus and car travel. Of course, much of this difference results from the far higher occupancy rates for Indian public transport, as well as the use of diesel.

A better comparison would be vehicle fuel use per seat-km or per tonne-km. In Hong Kong, the Kowloon to Canton Railway in the mid-1990s used only 0.15 MJ of electric power per tonne-km for traction and auxiliary power combined. Regenerative braking has enabled traction energy requirements to be halved, and since air and rolling resistance are low for rail, inertial resistance is the main power consumption component (Moyes, 1992). For a nominal 33% power plant conversion efficiency, primary energy use is then 0.45 MJ/tonne-km, compared wth the 1996 Camry value of 2.68 MJ/tonne-km (Weiss et al., 2000). So even today, Asian urban rail transport can deliver six-fold efficiency gains over existing car travel, with scope for further improvement by rail carriage mass reduction.

Public transport is not only more energy efficient than private car travel, but also far more land-use efficient. A single freeway lane can typically carry the traffic equivalent of around 2000 cars, or about 3000 car occupants, per hour (Moriarty, 2000). Several urban rail systems around the world carry 50,000 passengers on a single line, and Hong Kong's carries up to 80,000 at peak hour (White, 1995). Asia already has a number of heavily patronised metro systems, with more under construction, including one in Delhi (Das and Parikh, 2004). Buses can also be very land-use efficient. Indian studies suggest that existing bus services there can deliver 38 times more passenger-km per unit of road space than can cars (Bose, 2003). Express bus systems with their own right of way are much cheaper than heavy rail systems, and some systems can move up to 35,000 passengers per lane (Sperling and Classen, 2002). Interestingly, in view of the popularity of motor cycles in India and elsewhere in Asia, their road space efficiency was also found to be low. Land availability will continue to be an important constraint on traffic growth in large Asian cities, since technical fixes such as ‘Automated Highway Systems’ are unlikely to help much in the complex traffic systems of Asian cities (Moriarty and Kennedy, 2004).

Non-motorised passenger travel – walking and cycling – are already zero emission and zero oil travel modes. Asian cities still rely extensively on these transport modes, and most of the world’s bicycle manufacture and use is in Asia. Nevertheless, the share of these desirable modes is steadily declining in Asian cities (Newman and Kenworthy, 1989, 1999; Tiwari, 2003). Their users are subject to high levels of vehicle-caused delays, pollution, and traffic casualties. Increasingly, only the urban poor, with no other transport options, use them (Tiwari, 2003). These reductions in non-motorised travel are also part of the general decline in physical activity found worldwide, initially in the OECD countries, but now in Asia as well. Such reductions are in turn linked – along with diet changes – to greater obesity and its associated health problems (Popkin, 2004). More use of non-motorised travel could help reverse this trend (Higgins and Higgins, 2005).

The densely populated cities of Asia are ideally suited to urban transport systems built around public transport and non-motorised modes. They are tried and proven transport systems. (The author can attest to this, as even in low-density Melbourne he relies entirely on these modes.) They do not require the major technical breakthroughs that HFCVs or cellulosic ethanol need. Nor do they carry the risks that reliance on an ever-growing, imported petroleum supply faces. Finally, as has been pointed out for Delhi, the private mobility of car-owning households has been purchased at the expense of the rest, who now find these alternative modes more difficult and more dangerous to use (Tiwari, 2003). If Asian cities are to provide healthy and sustainable living environments, it will thus be necessary to realign all relevant government policies, not just transport, to achieve the desired changes. Health policy is an obvious case, given transport’s importance for respiratory diseases, exercise levels, and traffic injury. Land-use planning, including the location of industry, commercial and residential areas, is another area with major implications for transport planning. And if car travel is only to play a minor role in Asian cities, the future of Asian car industries will need to be reassessed.

6 Conclusions

In industrialising countries, personal income has long been the main constraint on widespread car ownership. However, incomes are rising rapidly in the cities of many Asian countries, so that traffic congestion and air pollution are replacing income as barriers to higher car ownership. As a result, Asian car ownership levels, with the exception of Japan, are low, so that Asia’s share of the world’s car fleet is only about half its share of world income. Further potential barriers to higher car ownership are global oil depletion and supply security, which could well be the leading constraint within a decade, and regional/global climate change.

More energy-efficient private vehicles, alternative fuels and propulsion systems, and more reliance on alternative transport modes have all been suggested as solutions to urban transport’s resource and environmental problems, both for Asia and elsewhere. Particularly in urban Asia, hybrid vehicles can offer appreciable gains in both energy efficiency and emissions reduction, but at increased cost. However, if car travel was to become the dominant travel mode, any likely improvements in fuel economy from hybrid vehicles would soon be overtaken by rising vehicle-km. Another suggested approach is to use other hydrocarbon fuels, or fuels derived from renewable energy, including hydrogen. All these fuels, like petroleum, will in future either be in short supply, or have their own adverse impacts on air quality or climate. No foreseeable changes to vehicles or fuels appear capable of solving private car travel's fuel supply or global climate impact problems.

Because of these various resource/environmental challenges, private car travel is unlikely to ever be the dominant mode in Asia's large cities. When the need for greatly increased land for vehicle movement and parking is also considered, a car-based urban future is even less probable. Instead, a combination of public transport, both electric rail and bus, and non-motorised travel appears to be the only feasible means of meeting the growing transport needs of Asian cities in a sustainable and equitable manner.

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Glossary

ASPO	Association for the Study of Peak Oil and gas
CNG	Compressed Natural Gas
EIA	Energy Information Administration (US)
EV	Electric Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GNI	Gross National Income
HFCV	Hydrogen Fuel Cell Vehicle
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
LPG	Liquefied Petroleum Gas
MJ	Megajoule
MIT	Massachusetts Institute of Technology

Mbd	Million barrels/day
NGL	Natural Gas Liquids
NO_x	Nitrogen Oxides
NPP	Net Primary Production
OECD	Organisation for Economic Cooperation and Development
SUV	Sports Utility Vehicle
UHI	Urban Heat Island
USGS	US Geological Survey
VOC	Volatile Organic Compounds