

# Gasoline Consumption and Cities

## A Comparison of U.S. Cities with a Global Survey

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**Gasoline consumption per capita in ten large United States cities varies by up to 40 percent, primarily because of land use and transportation planning factors, rather than price or income variations. The same patterns, though more extreme, appear in a global sample of 32 cities. Here, average gasoline consumption in U.S. cities was nearly twice as high as in Australian cities, four times higher than in European cities and ten times higher than in Asian cities. Allowing for variations in gasoline price, income, and vehicle efficiency explains only half of these differences. We suggest physical planning policies, particularly reurbanization and a reorientation of transportation priorities as a means of reducing gasoline consumption and automobile dependence.**

Assessments of United States oil dependence suggest that the widening gap between consumption and production is a cause for concern, given the U.S. government's deficit and potential political vulnerability in the 1990s (Abelson 1986; U.S. Department of Energy 1980). Conserving oil has been strongly advocated for other environmental, economic, and social reasons as well (Clark and Munn 1986; Energy Policy Project 1974). Policies to reduce oil consumption in the United States have successfully concentrated on stationary uses (e.g., industry and home heating) and improving vehicle fuel efficiency rather than on reducing the need for motor vehicle use. Studies rarely focus on cities, and those that do generally suggest

that only minimal energy savings would result from greater use of transit and land use changes (La Belle and Moses 1982; Sharpe 1982; Small 1980). Such studies tend to have a limited data base, as urban energy statistics are generally not available. Since cities are being built in patterns that last for 30 to 50 years, the implications for transportation energy use should at the very least be better understood. As Beaumont and Keys (1982) state, "[T]here has been insufficient examination of what an energy efficient urban form is actually composed of and how such a state can be reached given the present arrangements."

This article summarizes a study funded by the Australian government (Newman and Kenworthy 1988a) to evaluate physical planning policies for conserving transportation energy in urban areas by comparing how motor gasoline is used in 32 cities around the world. The data on ten United States cities are extracted and analyzed before they are compared with data from the global sample.

The scope of the broader study, involving the collection of data from 32 principal cities in North America, Australia, Europe, and Asia on land use, automobile use, transit, and other transportation factors like parking facilities and road length, has provided an important data set on cities covering 1960, 1970, and 1980. It can be used to examine a range of urban issues besides gasoline use—e.g., air pollution (directly related to gasoline use) and road accidents (directly related to auto use). Although this article does not

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include an examination of all of these issues, it does suggest that reducing gasoline use through physical planning will achieve other important gains related to the impact of the automobile on cities.

## Data collection

Comparative studies of cities around the world are rare, mainly because of the difficulty of collecting data. Most transportation, energy, and planning data are collected on a state or national basis, although each city generally has that data in disparate physical planning and transportation agencies. The data in this study were collected over a five-year period primarily by visiting each city, sometimes twice, with considerable follow-up correspondence. All data were verified by other sources, e.g., gasoline consumption was verified by using vehicle miles of travel (VMTs) for each city and national vehicle fuel efficiency data adjusted for average speed. To achieve comparable land use data, we defined urban areas to exclude all rural land, such as farms, forests, undeveloped land, and large bodies of water. Except in the case of New York, the U.S. city referred to is the standard metropolitan statistical area (SMSA) with the previously mentioned rural land uses excluded, i.e., the U.S. Bureau of the Census "urbanized areas" are used to define overall densities. "Central area" refers to the old, highly built-up central business district defined by each city on the basis of census tracts or traffic planning zones. "Inner area" refers to the pre-World War II urban area; in practical terms, for six of the cities, it is the original city lying at the heart of the urban region, e.g., the city of Detroit. The exceptions are Boston, where inner area is defined as Suffolk County; Washington, D.C., where the inner area is the District of Columbia; Phoenix, where the city authority defined the 1940 urban boundary with census tracts; and Houston, where the transportation authority defined the inner city as the area within the Interstate Loop I-610. Details of the methodology, including precise definitions appear in our book (Newman and Kenworthy 1988a).

In this article we first analyze the ten U.S. cities in the sample in order to show the major thrust of the study and to minimize any problems that might develop from international comparisons. We then amplify the main conclusions by comparing them with the global sample.

## The United States sample

The per capita gasoline consumption in U.S. cities (Table 1) varies by some 40 percent between the newer and more automobile-oriented cities like Houston and the older cities like New York. This pattern can be compared to factors typically considered in economic analyses, such as income, gasoline price,

and car ownership. Median family income in the city shows no correlation whatsoever with gasoline consumption ( $-0.1219$ ), though consumption is significantly related to gasoline price ( $-.6151$ ). Vehicle ownership is significantly correlated ( $+0.6574$ ), but is not independent from other urban structure parameters, which previous studies have shown to determine how much a car is needed (Pushkarev and Zupan 1977; Button, Fowkes and Pearman 1980; Hillman and Whalley 1979, 1983). For example, vehicle ownership is not significantly correlated with income in the ten U.S. cities ( $0.3863$ ).<sup>1</sup> This article concentrates on the urban structure parameters, and therefore its focus, as illustrated in Tables 1 and 3, is on the physical planning parameters that were expected to have some role in the relative dependence of a city on automotive gasoline.

## Land use planning parameters

The size of a city could be expected to have an influence on transportation patterns. However, in this sample the correlation of gasoline use with size—both population size and urban area—are weakly significant but negative; smaller cities appear to have higher, not lower, automobile travel, which is the reverse of what one would expect. This correlation suggests that, at least in this sample of relatively large cities, size is less important than other physical planning parameters.

Population and job density are key land use parameters. Together they show how intensively a city uses its land. Studies have shown that, the more intensive the land use, the shorter the distances of travel, the greater the viability of transit (more people per stop and hence better service), the greater the amount of walking and biking, the higher the occupancy of vehicles and, overall, the less need for a car (Newman and Kenworthy 1980, 1985; Hillman and Whalley 1979, 1983). The relative intensity of land use in the ten U.S. cities is clearly correlated with gasoline use overall and in the inner and outer areas. The strongest relationship is with the population density in the inner area; in fact, the largest variations in land use in these U.S. cities are between the inner areas of places like Houston and Phoenix, which contain around 8 people per acre and 10 jobs per acre compared with New York, which contains more than 40 people per acre and 20 jobs per acre. The overall intensity of activity in New York and Chicago is around double that of Houston and Phoenix. The outer areas of all U.S. cities, including New York, have uniformly low densities (although with some gradation); on average the inner areas are four to five times as dense as the outer areas.<sup>2</sup>

These patterns suggest that the urban structure within a city is fundamental to its gasoline consumption. Some data within particular cities confirmed this. Table 2 shows that the New York tristate region

**Table 1. Gasoline use and land use variables in U.S. cities (1980)**

City	Density (persons or jobs/acre)				Central city strength			Other	
	Gasoline gallons per capita	Total	Inner	Outer	Jobs in city center	Proportion of jobs in city center (%)	Proportion of population in inner city (%)	Average to-work trip length (miles)	
Houston	567	3.6	8.5	3.2	173,540	12	17	9.3	
Phoenix	532	3.2	7.7	3.2	25,920	4	4	8.1	
Detroit	503	5.7	19.4	4.5	110,700	7	30	8.7	
Denver	483	4.9	7.7	4.1	100,330	12	31	6.8	
Los Angeles	445	8.1	12.1	6.9	152,920	5	31	9.3	
San Francisco	422	6.1	23.9	5.3	273,160	17	21	7.5	
Boston	413	4.9	18.2	4.1	218,210	16	24	6.2	
Washington	390	5.3	17.8	4.5	268,700	16	21	8.7	
Chicago	367	7.3	21.9	4.5	388,280	12	42	8.1	
New York	335	8.1	43.3	5.3	1,930,000	23	40	10.6	
Average	446	5.7	18.2	4.5	364,180	12	27	8.1	
Correlation with gasoline		-.7390	-.7803	-.5006	-.6367	-.6908	-.6451	-.073€	
Significance		0.007	0.004	0.069	0.023	0.013	0.021	0.419	

**Table 3. Modal split and automobile provision factors in U.S. cities (1980)**

City	Modal split				Automobile provision			
	Transit passenger miles	Total passenger miles on transit <sup>b</sup> (%)	Journey to work <sup>c</sup> (%)	Walk-bike	Parking spaces <sup>d</sup> (per 1,000 CBD workers)	Average speed of traffic <sup>e</sup> (mph)	Average speed of transit (mph) <sup>f</sup>	Street car/light rail
Houston	60	0.8	3	3	370	32	14	—
Phoenix	41	0.5	2	3	1033	26	14	—
Detroit	70	0.8	4	3	473	27	13	26
Denver	135	1.8	7	5	498	28	13	—
Los Angeles	239	2.7	8	4	524	28	13	—
San Francisco	575	6.6	17	6	145	29	14	9
Boston	322	4.0	16	10	322	24	11	24
Washington	383	142	14	5	264	24	11	12
Chicago	603	8.0	18	6	91	26	11	29
New York	798	14.1	28	8	75	22	9	22
Average	324	4.4	12	5	380	27	12	26
Correlation with gasoline	-.9062	-.8455	-.9234	-.7529	+7.140	+7.781	+8.632	+2.607
Significance	0.000	0.000	0.000	0.006	0.010	0.004	0.001	0.309

a. All transit rides including private buses.  
 b. Private car passenger miles from VMT and average auto occupancies.  
 c. U.S. census data.  
 d. All road types including local roads.  
 e. On-street and off-street parking.  
 f. Derived from each city's traffic model.  
 g. Bus includes trolley buses. Train includes all separated heavy rail systems.

gasoline use is 335 gallons per person. However, for the inner city residents (city of New York), this amount reduces to around 153 gallons per person and, for the 1.4 million inhabitants of Manhattan, gasoline use drops to an extraordinary 90 gallons per person. The link to density is clear. In Denver the 240,000 exurban residents who live at very low density on the fringe of the city consume some 1,043 gallons per capita, 12 times the Manhattan consumption.

The strength of the city center can also affect transportation patterns—the more jobs in the city center the more viable generally is transit, which has its justification in large numbers of people all going to one place (Thomson 1977). The data in Table 1 support this idea with significant correlations between gasoline use and both the number and the proportion of jobs in the city center. They also support the hypothesis by Thomson that a city center cannot grow much beyond 120,000 jobs based around automobile access. The patterns of transit use are given in Table 3 and are examined further on in this article.

The other land use parameters explored in this study are the proportion of the population living in the inner city and the average journey-to-work trip length. The latter factor is related to the density and size of the city. The inner city proportion parameter gives an idea of how much of that city is in the pre-World War II form, prior to the assumption of large-scale automobile use, i.e., where densities are higher and land use is mixed residential/commercial/industrial (Duxbury et al. 1988; Witherspoon 1976; Van der Ryn and Calthorpe 1986). Table 1 shows that there is a significant negative correlation of gasoline use with the proportion of population living in the inner city. The overall metropolitan journey-to-work trip length does not reveal any significant relationship to gasoline use. However, this parameter becomes more meaningful when we examine the perspective of other types of cities in different parts of the world.

### Transportation planning factors

The use of transit, walking, and biking are related not only to the intensity and siting of urban activity but also to the extent to which a city provides for its automobile and its nonautomobile modes. Table 3 brings out these patterns clearly. The usage of non-automobile modes (both transit and walking or biking) is strongly correlated with gasoline use, particularly in the journey-to-work modal split data, which highlight the variation from the Houston-Phoenix-Detroit type of city, which has more than 93-percent car use, down to New York, which has only 64-percent car use. This pattern is even more evident within New York, where private car use for work trips drops to 31 percent for inner city residents and to 12 percent for Manhattan (New York County) residents.

Traffic speeds in the New York inner city average

**Table 2. Gasoline use and urban density in New York by region (1980)**

Area	Gasoline use (gallons/capita)	Urban density (persons/acre)
Outer area	454	5.3
Whole urban area (Tristate metro area)	335	8.1
Inner area (City of New York)	153	43.3
Central city (New York County—mainly Manhattan)	90	101.6

16 miles per hour and in Manhattan 10 miles per hour, coinciding with the very low per capita gasoline consumption of the residents given previously. This pattern of lower gasoline use per capita in areas with lower average traffic speeds is confirmed by the overall pattern in Table 2 and does not support studies (and the view of most traffic authorities) that suggest there will be fuel savings when average speeds are increased due to better vehicle efficiency (Newman and Kenworthy 1984). Rather, this pattern confirms the picture being developed here that urban structure is a more fundamental determinant of gasoline use than is vehicle efficiency. We elaborate on this point in the discussion of the larger sample of cities.

Average speed data highlight the relative provision of road and parking infrastructure. The availability of roads and central city parking follows the pattern of gasoline consumption with highly significant positive correlations. The average speed data also highlight the importance of a separated rail transportation alternative. These data show clearly that buses are much slower than the overall traffic speed but that trains mostly can compete with the automobile for time savings. These speed data do not take account of time lost getting to and from bus stops, rail stations, or car parks.

### The low-consumption city

A stylized picture emerges of a low transportation-energy city with a dense form, a strong center, and intensively utilized suburbs (especially the inner area) that provide the backbone for a significantly better transit system and more walking and biking. The outer areas of U.S. cities appear to be quite similar in density (and car use) to those cities with strong inner areas and transit (e.g., New York and Chicago), which are able to extend their commuter trains to outer suburbs, so that at least some journeys are less demanding of an automobile.

There are, of course, many problems in suggesting that one city should become more like another. Nonetheless, the data suggest that there is a theoretical potential for fuel savings of some 20 to 30 percent in

cities like Houston and Phoenix, if they were to become something more like Boston or Washington, in urban structure. This would require a modest increase in the intensity of urban activity and the provision of a basic rail transit system. With more extreme changes in land use, such as increasing the density of population and jobs to the level of the inner areas of New York, much higher fuel savings would seem likely. Such savings would be considerably higher than the few percentage points generally predicted for transit and land use changes (Small 1980; Sharpe 1982). It appears from this study that the effects of land use and transit are more strongly interconnected than expected and that substituting car trips by transit results in more than just improved technological efficiency. Rather, it fosters a total change in transportation patterns, including an increase in walking and biking, and shorter distances for all modes, including car trips.

### The global sample

The relationships between gasoline use in cities and land use/transportation factors can be further developed by expanding the comparison to a sample of major cities around the world. In order to summarize the data for the global sample, we placed the cities in regional groups. In this global comparison the range of gasoline use extends much further than in the United States sample. The average U.S. city uses nearly double the per capita gasoline consumed by Australian cities, a little less than double the gas used

in Toronto, four times the gas consumed in the average European city, and ten times the average of the gas used in the three "westernized" Asian cities. We included Moscow in the sample to show an example of a city where there are almost no private cars (only 2 percent of the city go to work in a car) and hence where there is virtually no gasoline use; however, because Moscow is so fundamentally different from other cities, and because other data on Moscow are limited, it has been excluded from most of the analysis.

### Economic factors

The immediate response to any such comparisons across nations is to try to find variables like gasoline price, income, and relative vehicle efficiency that can help explain the large differences. There are significant correlations between gasoline use and price (-.7704), income per capita (0.7994), and vehicle fuel efficiency (-0.8830).<sup>3</sup> Therefore, we will examine these variables to see how important they are before pursuing urban structure and the other factors discussed in the previous section.

Many econometric analyses have been conducted to determine the way price and income relate to gasoline. These analyses have been used here to calculate how much more gasoline would have been consumed if the other cities had had U.S. gasoline prices, incomes, and vehicle efficiencies. The adjusted values using short-term (2 years) and long-term (20 years) elasticities are given in Table 4.<sup>4</sup> It could be argued that the long-term adjusted gasoline values

**Table 4. Average values for gasoline use in cities by region (1980) compared to adjusted values<sup>a</sup>**

	Actual gasoline use (gallons per capita)	Adjusted gasoline use for U.S. gasoline prices, incomes, and vehicle efficiency (gallons per capita)		Difference between U.S. gasoline use and adjusted gasoline use by other cities (%)	
		Short-term elasticities	Long-term elasticities	Short-term elasticities	Long-term elasticities
U.S. cities	446	446	446	—	—
Australian cities	227	293	333	52	25
Toronto	265	228	199	49	55
European cities	101	130	237	71	47
Asian cities	42	158	94	87	79
Average for non U.S. cities	131	163	237	63	47

a. Gasoline consumption elasticities used were:

	short-term	long-term	Sources: see note 4.
gasoline price	-.20	-1.0	
incomes	+.11	+0.6	

As gasoline consumption elasticities include a component due to vehicle efficiency, it is necessary to subtract this when adjusting other cities for U.S. vehicle efficiencies. Otherwise it would be accounted for twice. Vehicle elasticities used were:

	short-term	long-term
gasoline price	+0.11	+1.0
incomes	-0.11	-1.0

Vehicle efficiencies used were national values adjusted for average speed in each city. In all cases vehicle efficiencies in the longer term become more than equivalent to U.S. levels and hence the vehicle efficiency factor in the long term is canceled out. Income data are real-product data adjusted for purchasing power parities.

overstate the effect of the economic variables (as separate from urban structure variables), for after 20 years urban structure would have adjusted to minimize travel to some degree. However, they do provide an upper bound. The discrepancy between actual U.S. gas use and adjusted gas use by other cities in Table 6 suggests that the price, income, and vehicle efficiency variables leave unexplained a large part of the difference between U.S. cities and others. On average the economic factors cannot account for 63 percent of the gasoline use in the short term and 47 percent in the long term. For Australian cities only 25 percent is left unexplained, but in Asian cities it is nearly 80 percent. We would suggest that urban structure, directly under the control of physical planners, is central to explaining the patterns in gasoline use and automobile dependence.

One of the key features drawn out by the economic adjustment data is the place of Toronto, which resembles a European city in its fuel use. Toronto is a less car-dependent city than are U.S. and Australian cities (6,118 passenger miles per capita by car in Toronto compared with 7,768 passenger miles in the U.S. and 6,634 passenger miles in Australia), but its vehicle fuel efficiency and gasoline price were lower than in the U.S. in 1980. The reasons for Toronto's low car usage are examined below.

The role of the economic variables will be addressed further on in this article. At this point we will look at the importance in the global sample of the physical planning factors that were found partially to explain U.S. city gasoline variations.

### Land use planning factors

The intensity of urban activity (Table 5) measured by the density of population and density of jobs is strongly correlated with gasoline use in both inner and outer areas. Australian cities resemble U.S. cities in their density patterns. Toronto, on the other hand, has a strong inner area similar to that of the five U.S. cities with the lowest gas consumption, but its outer area is more compact in population and jobs by nearly three times on average. Thus, Toronto has land use characteristics tending more towards those of a European city. From observation, a key difference between Toronto and U.S. cities seems to be the strong subcenters developed in the suburbs around transit stations. Cervero (1986) confirms this in his detailed assessment of how Toronto and other Canadian cities use transit to guide urban development. European cities on average have four times the intensity of urban activity overall compared with U.S. cities, their inner cities being nearly double and their outer areas nearly four times that found in the United States. Asian cities are even more extreme, their urban land being more than ten times as intensively utilized. Hong Kong appears

to be the highest-density city in the world, with an overall population density of just under 120 people per acre, and a density of over 400 people per acre in its inner area.

Figure 1 shows the link between gasoline use and population density. The most obvious feature of this curve is the exponential relationship. The same shape is found when the gasoline data are adjusted for the price, income, and vehicle efficiency factors. The relationship suggests a strong increase in gasoline consumption where population density is under 12 people per acre. This relationship is conceptually quite possible, as low density appears to have a multiplicative effect, not only ensuring longer distances for all kinds of travel but making all nonautomobile modes virtually impossible, since many people live too far from a transit line and walking and biking become impossible.

The central city strength pattern is less obvious than the density relationship. There is a significant negative correlation between gasoline consumption and the proportion of jobs in the city center, but not for the absolute number of jobs. However, the differences in central city land use are not as marked in the total sample as are the differences in land use throughout the rest of the city. This suggests that the overall density is more important for travel characteristics than is the centralization factor.

There is probably another reason for the less clear effect of central city strength on gasoline use as measured by jobs. U.S., Australian, European, and Asian cities all concentrate jobs in city centers, in some cases to a similar extent. For example, Houston, with 174,000 jobs in the center and Hamburg with 187,000 are very similar. However, these two cities are vastly different in their modes of access to the city center and parking; Houston is almost totally automobile-oriented, with ample parking, and Hamburg is extremely rail-oriented, with limited parking. Many such comparisons can be drawn from our detailed data. They suggest that it is largely the transportation policies applied to central cities that determine whether or not a significantly centralized work force is going to have a positive or negative effect on gasoline use. We have not evaluated the role and importance of strong subcenters within the urban area in these data. However such an evaluation could be a valuable exercise, as subcenters could be the means for more intensive outer area land use.

The proportion of population living in the inner city is also significantly correlated with gasoline use in the global sample. This correlation highlights again the importance of this inner city type of land use where travel distances are shorter. Unlike the U.S. sample, the global sample shows a significant positive correlation of journey-to-work trip lengths with gasoline use. Distances in European cities are generally 40 percent shorter than in the North American and

**Table 5. Gasoline use and land use variables in global cities (1980)**

City	Gasoline gallons per capita	Density (persons or jobs/acre)				Central city strength			Other	
		Total	Inner	Outer	Other	Jobs in city center	Proportion of jobs in city center (%)	Proportion of population in inner city (%)	Average to-work trip length (miles)	
U.S. cities	446	5.7	18.2	4.5	2.0	364,180	12	27	8.1	
Australian cities	227	5.7	9.7	5.3	1.6	107,736	16	17	7.5	
Toronto	265	16.2	23.1	13.8	5.8	142,645	13	36	8.1	
European cities	101	21.9	36.8	17.4	8.1	265,505	19	41	5.0	
Asian cities	42	64.8	18.8	46.6	17.8	785,225	19	32	2.5	
Moscow	3	56.2	—	—	—	—	—	—	—	
Correlation with gasoline <sup>a</sup>		-.5778	-.3917	-.5751	-.5912	-.1026	-.5027	-.4577	+ .7620	
Significance		0.000	0.0150	0.000	0.000	0.291	0.002	0.005	0.000	

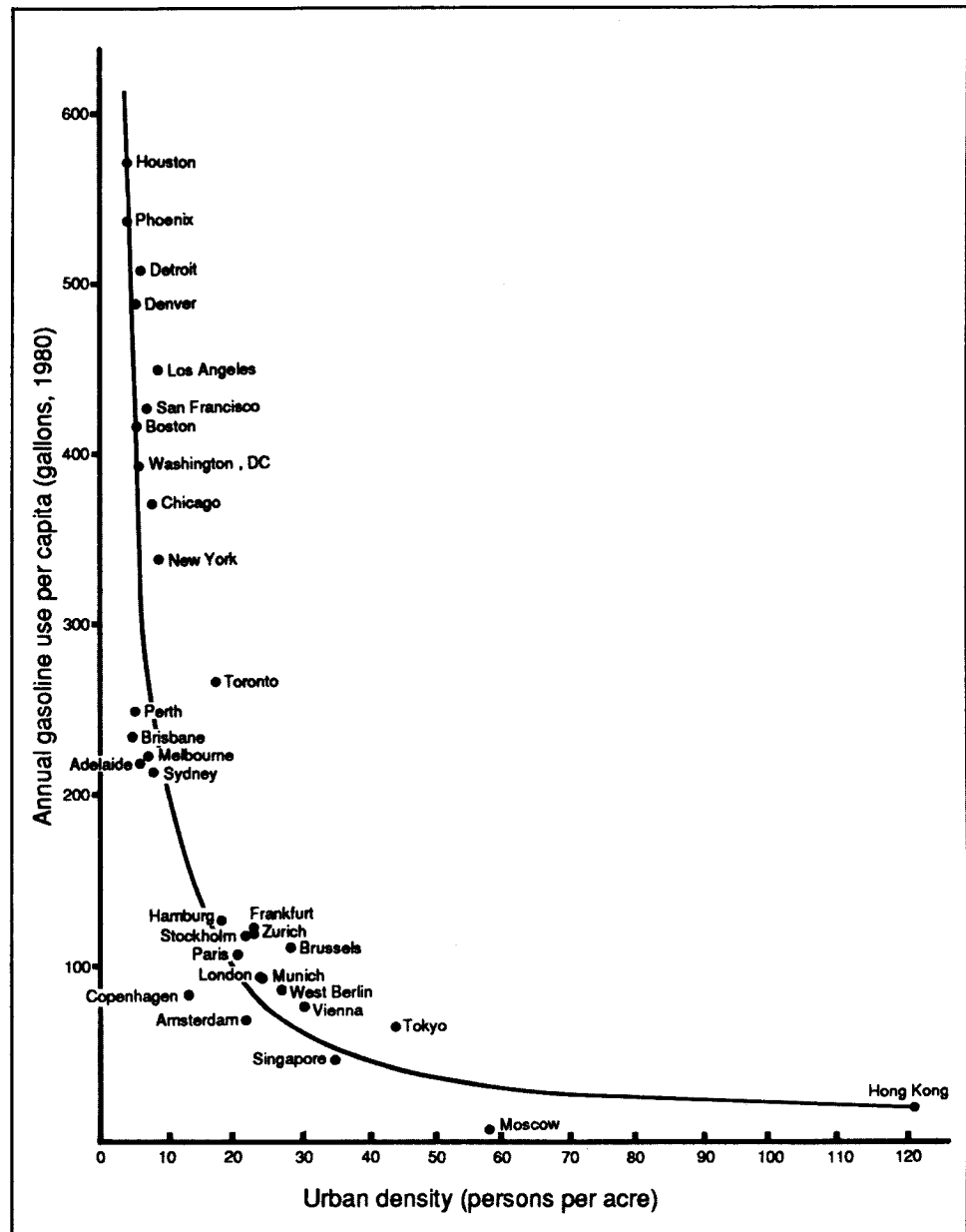
a. Correlations are on all 32 separate cities in the sample.

**Table 6. A comparison of modal split and automobile provision factors in global cities (1980)<sup>a</sup>**

City	Modal split				Automobile provision			
	Total passenger miles	Total passenger miles on transit (%)	Journey to work (%)	Parking spaces (per 1,000 CBD workers)	Average speed of traffic (mph)	Bus	Train	Street car/light rail
U.S. cities	324	4.4	83	380	27	12	26	11
Australian cities	532	7.5	76	327	27	13	24	14
Toronto	1,227	16.7	63	198	—	12	21	10
European cities	1,112	24.8	44	211	19	12	27	11
Asian cities	1,900	64.1	15	67	15	9	22	8
Moscow	>2,647	>95	2	—	28	13	>26	11
Correlation with gasoline <sup>b</sup>	-.7191	-.7530	+ .8733	+ .5754	+ .7034	+ .2734	-.0481	+ .2602
Significance	0.000	0.000	0.000	0.000	0.000	0.072	0.410	0.184

a. All variables defined in Table 3 (rail means train and streetcar/light rail).

b. Correlations with gasoline use per capita are for all 32 separate cities in the sample.



**Figure 1. Gasoline use per capita versus population density (1980)**

Australian cities, which have sprawled extensively through construction of post World War II outer suburban housing. In Asian cities average journey distances are half those in European cities. This feature helps to explain the high proportion of walking trips in these cities.

**Transportation planning factors**

Table 6 shows the same strong relationships as seen with U.S. cities between gasoline use and both the use of transit (especially rail) and the amount of provision for the automobile.

Australian cities with land use similar to that of U.S. cities have a higher usage of transit, although they have a similarly high provision of roads and parking spaces. The significant difference in gasoline

use between Australian and U.S. cities may well be explained by this difference in transit, which is perhaps due to a higher provision of service (an average of 35.0 vehicle miles per capita in Australia compared with 18.6 vehicle miles in the U.S.).

Toronto has a much stronger transit system ( 50.4 vehicle miles of service per capita) than do U.S. or Australian cities, a feature consistent with its denser land use; its provision for automobiles is also much less than that in U.S. and Australian cities. The diversity of its transit systems, which include commuter rail, subway, modern trams on-street and new LRTs on separated tracks, electric trolleys, and diesel buses (as well as comprehensive cycle ways), provides a powerful comparison to nearby Detroit, which has an almost complete commitment to the automobile. The per capita gasoline consumption in Detroit is double

that in Toronto; transit use is 0.8 percent of total passenger miles in Detroit, compared with 16.7 percent in Toronto. However, the difference in gasoline consumption in Detroit and Toronto cannot be explained simply by the difference in transit use. For example, if all of Toronto's transit users transferred to car the per capita use of gasoline would increase by 53 gallons, making Toronto's usage still 184 gallons per capita lower than that of Detroit. The Toronto transit system is part of an overall more energy-efficient city, despite Toronto having lower gasoline prices in 1980 and less fuel-efficient vehicles than the U.S. Indeed, Toronto is one of the few cities in the world with well-developed policies for transportation energy conservation based on land use strategies (Municipality of Metropolitan Toronto, 1984).

European cities show even greater efficiency; 25 percent of all passenger travel is by transit and only 44 percent use a car for the journey to work. The importance of walking or biking in these more compact cities is highlighted by the fact that 21 percent use these modes for their work trip. In Amsterdam the proportion rises to 28 percent and in Copenhagen to 32 percent. The provision of roads and central city parking is expectably much less generous than in U.S. and Australian cities.

Asian cities again show the most extreme pattern, with nearly two-thirds of their total transportation passenger miles on transit. The car is only a minor (15 percent) factor in work journeys, coming after walking and biking (25 percent). In the modern city of Tokyo there are one sixth of the central-area parking spaces per 1,000 jobs and nearly a quarter of the roads that are in U.S. cities: only 16 percent use a car to go to work.

The average traffic speed is strongly correlated with gasoline use per capita and is positive, not negative, as predicted by those who study only the effects of congestion on individual vehicles. This tradeoff between fuel-efficient traffic and fuel-efficient cities is confirmed at a local level by the data on regions of New York (Table 2). The tradeoff was examined in a detailed analysis by suburb in the Australian city of Perth. Here we found that, in central areas, vehicles were 19 percent less efficient than average but that residents in these accessible, although congested, areas used 22 percent less fuel. In outer areas, on the other hand, vehicles were 12 percent more efficient than the urban average but residents had to drive so much more that they used 29 percent more fuel overall (Newman and Kenworthy 1988b).

The data in Table 6 also show that a rail-based transit system can compete with the automobile and that in Europe and Asia train speeds are generally faster than the average traffic speed. Bus travel is universally slower than 15 mph and cannot be considered competitive with car travel. The much slower

speeds of the streetcar do not diminish their importance in European cities, as streetcars play an important role in short local trips linking in to major train stations that again lower car use (Vuchic 1985). Central area pedestrianization, which is so extensive and so popular as a means of revitalizing central areas of European cities, is made possible by the strong transit operations in these cities based primarily around trams and trains (Vuchic 1981).

These clear relationships between gasoline use and a range of physical planning and transportation variables confirm the model of a gasoline-conserving urban structure developed earlier with the ten U.S. cities. In this model the city is compact, with a strong city center, combined with a commitment to transit (especially rail) and other nonautomobile modes, and to restraint in the provision of automobile infrastructure. Further clarification of the relationships would help. However, the relationships already established begin to suggest a number of policy areas in which cities like those in the U.S. (and Australia) could respond to the challenge of using less gasoline, as well as to the other benefits that flow from a less automobile-oriented city.

## Policy implications

Policy studies on gasoline use derive mainly from simulation studies or econometric models. Simulation studies that have examined urban land use or transit changes have generally suggested that only minimal savings would be possible. For example, Small (1980) suggests that an energy-induced land use control that resulted in densities of 15 units per acre, compared with the current U.S. average of 5 units per acre would reduce automobile usage for work trips by only 1.4 percent after 6 years. Sharpe (1982) suggests energy savings of only 11 percent if urban density in Melbourne is tripled. None of the assessments in these studies has taken into account the sort of urban data contained in the present study. The results of our study suggest that simulations and policy studies concerning the effect of density on transport will need to consider the much more extensive pattern of changes occurring from increased urban activity and lowered automobile dependence, since, in their joint effect, these changes appear to lead to much higher potential gasoline savings. In particular, as Figure 1 shows, there is an exponential relationship between gasoline use and density, suggesting that major fuel savings are possible as cities move from the 4 to 6 people per acre to the 12 to 14 people per acre range.

## Economic versus physical planning factors

Econometric models are based on correlations of variables considered to be the key determinants of gasoline use. Gasoline models have nearly all been

based on national data and all show that price, income, and vehicle efficiency are sufficient to explain their data. The problem with using econometric models to attempt to explain variations in urban gasoline consumption is that these models are assuming urban spatial variations, and modal split patterns can be accounted for solely by gasoline price and income variations. On a national basis this is broadly the case, as rural driving will mainly be determined by these variables and in general there is a correlation between wealth and urban space, i.e., money tends to buy space. However, there are many important variations in this pattern, due to:

- Constraints in urban sites, such as New York;
- Social and cultural factors, such as those in European cities, where frequently money buys location, not space (and a central location is often preferred;<sup>5</sup> and
- Such factors as a good transit system, which concentrates land use and provides a real alternative to the automobile because it saves time.

Omitting these factors means that policy developed from econometric models will have limited application to transportation in cities. This would explain why in the sample of U.S. cities there is no significant correlation between gasoline consumption and income or between vehicle ownership and income, and why there was the same lack of correlation in a previous study of Australian cities (Newman and Kenworthy 1980).

These factors are extremely important where policy is concerned. The econometric models suggest that there is little that can be done to reduce gasoline consumption other than taxing gasoline and vehicles or legislating for better vehicle fuel efficiency. This study, on the other hand, suggests that there are a variety of policies with potential to save fuel. They include:

- Increasing urban density;
- Strengthening the city center;
- Extending the proportion of city that has inner-area land use;
- Providing a good transit option; and
- Restraining the provision of automobile infrastructure.

These parameters are in the direct control of physical planners. In the remainder of this article we discuss the two main physical planning policy areas that appear to follow from the data analysis: reurbanization and reorientation of transportation priorities.

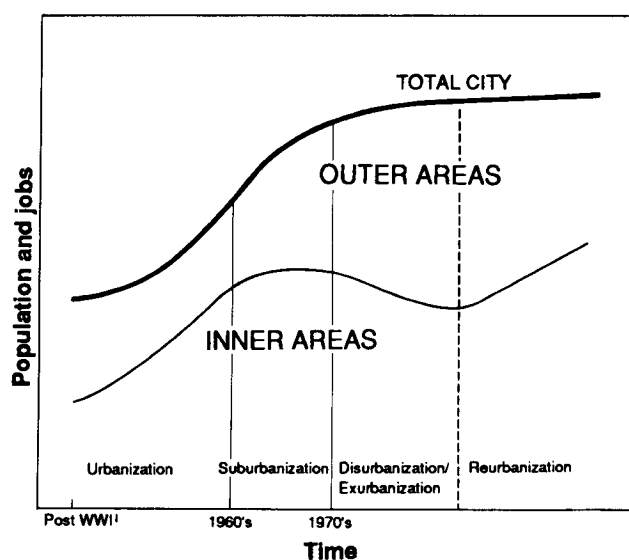
### Reurbanization

Increasing the intensity of urban activity within the present urban area rather than continuing to push

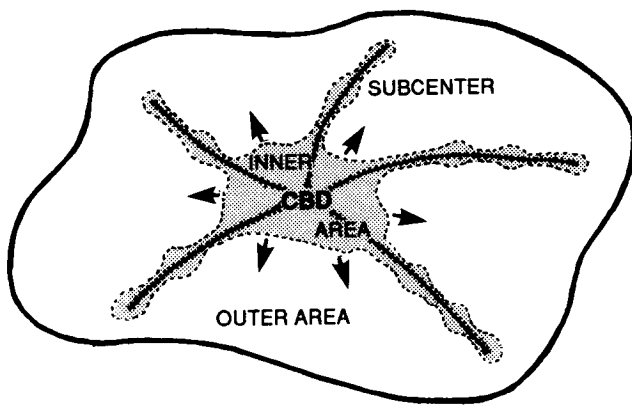
into green-field rural areas has come to be called reurbanization. It follows the pattern of urban trends outlined in Figure 2. In the reurbanization process population and jobs once again begin to grow in inner areas and outer areas concentrate development and begin to take on more of the intensity and mixed character of the old inner areas. Figure 3 illustrates this phenomenon and also highlights the importance of growth along major transit lines.

Reurbanization is discussed mainly in Europe and is only minimally considered for its fuel savings; the principal motivations usually are its economic and social benefits—a vital and attractive central and inner city and better utilization of the existing urban infrastructure (v.d. Berg et al. 1982; Klaassen, Bourdrez, and Volmuller 1981). In addition, reurbanization is considered to help diminish vehicle emissions that contribute to acid rain and smog. Despite the suburbanization processes of the postwar period, most European cities have not deconcentrated as rapidly as have cities in the United States (the densities in this study reflect this difference). Likewise, European cities do not face the same inner and central city crises (Heinritz and Lichtenberger 1986). Nevertheless, there is an ongoing effort to reurbanize. Many case studies outline evidence of successful reurbanization in Europe (Tanghe, Vlaeminck, and Berghoef 1984; v.d. Berg, Klaassen, and v. d. Meer 1983).

The same trend to redevelop, restore, reuse, and more intensively develop urban land is evident in U.S. cities, but the trend is in its infancy. Brian Berry (1985) calls U.S. reurbanization efforts “islands of renewal in seas of decay.” Nevertheless, the potential for the reurbanization of U.S. cities is clear; in fact, this study’s comparison of U.S. cities with other global



**Figure 2. Reurbanization as a fourth phase in urban development**



**Figure 3. Reurbanization through extension of the inner area and development along rail lines**

cities shows the potential to be quite considerable. Recent data show that the deconcentration of people and jobs from U.S. cities has reached the slowest rate since the 1920s (Macauley 1985) and that the return of younger people to the city is becoming demographically evident (Dynarski 1986). These studies suggest that the return to the city will probably proceed due to factors such as lifestyle preference rather than economics. However, other studies are now showing that trends in technology (towards more office and service-oriented employment) and demography (towards fewer households with children) are aiding the process (v.d. Ryn and Calthorpe 1986).

Working against a revival of the inner city are the problems of the concentrated racial and poorer communities that are in the majority in most U.S. inner cities (Peterson 1986). These communities have expressed fear of gentrification by upper middle class whites taking over cheap inner city housing (Purnick 1986; Celis 1986). The solution, at least in theory, would appear to be to reurbanize through building additional inner city housing. The value of reducing infrastructure needs on the urban fringe is obvious. A policy generating creative ways of building more central and inner city housing and forging new and more integrated communities appears to be crucial to a variety of concerns besides gasoline conservation.

San Francisco and Portland have made recent advances in reurbanization through creating new housing and jobs in their central cities. San Francisco has had a long tradition of central city living, with a 1980 population of almost 34,500 in a central business district (CBD) of 946 acres, compared with Phoenix, Houston, Denver, Detroit, Perth, Adelaide, Los Angeles, and Brisbane, which have an average of just over 5,000 people in a CBD area of 924 acres. The density of jobs has not suffered, as San Francisco had 273,000 jobs in 1980 compared with 96,000 on average for the other eight cities. San Francisco is now building its Mission Bay project on 300 acres of waterfront

land adjacent to downtown; it will house over 15,000 people and will have millions of square feet for office, research and development, and retail activity.

Portland, Oregon, is an example of a smaller U.S. city beginning to reverse its previous land use patterns through the redevelopment of a former freeway reserve in the Banfield corridor with a light rail line and thousands of new homes from the city center to a new subcenter at the end of the line. Twenty percent of all new homes in the eastern county are expected to be within walking distance of the new transit system. This example represents not only a commitment to reurbanization but also a reorientation of transportation priorities (Edner and Arrington 1985).

### **Reorientation of transportation priorities**

Although land use provides the framework for a city's transportation system, the actual patterns that emerge can of course be altered to some degree by the priority given to various modes. Many European cities are as compact as Amsterdam and Copenhagen, but these two are noted for strong commitments to bicyclists and pedestrians. Vienna's priorities were summed up by its mayor when he stated that "unlimited individual mobility . . . is an illusion," that "the future belongs to the means of public transportation," and that the need for public transportation will be "a driving force of city renewal" (Gratz 1981). Australian cities show a greater commitment to transit than do most U.S. cities with comparable land use. Within the U.S. the urban structure of cities such as Los Angeles and Detroit could support much more transit use, but these cities have obviously directed their priorities in the past to automobiles. For example, Detroit has an inner area population density that approaches that of Toronto, yet it provides only one fifth of the transit service per person.

A reorientation of transportation priorities in U.S. cities would include elements of the following policies:

**Upgraded and extended transit.** The technology and management structures for high-cost or low-cost separated-way transit systems have been adequately demonstrated in U.S. cities and elsewhere, with both positive and negative assessments (Vuchic 1981; Small 1985; Hall and Hass-Klau 1985). However, such systems—especially new light rail options—are increasing in popularity as a means of coping with high- and medium-capacity transportation requirements. To make transit a more fundamental part of the U.S. city will require a major commitment of planning and capital not unlike the commitment that has been more recently shown to highway building. The full benefits of such transit systems will be realized only when land use is allowed and encouraged to concentrate around transit stations, as has occurred around Washington's Metro (Metropolitan Washington Council of Governments

1983). Transit authorities can also help to pay for their systems by entrepreneurial activity on their land, such as development above and around stations.

The sheer inadequacy of totally automobile-dominated transportation is evident in the fact that many West Coast cities like San Diego, Los Angeles, San Jose, Sacramento, and Portland, after years of growing car use, have recognized the need for rail systems. Even Houston has now opted for a rail system. Such changes will play only a minor part in the short-term future of these cities, but they signal the beginning of an effort to build a less auto-dependent, fuel-hungry city.

**Increased pedestrianization and bicyclization.** The cheapest and most fuel-efficient transportation modes rarely achieve much priority in an automobile-oriented society. But, where land use is sufficiently concentrated, the opportunities for more walking and biking can be greatly encouraged by improvement of facilities. This task can include enhancing separation through establishing pathways and bike lanes and, particularly, through pedestrianizing central cities. Planning for linkages between transit and these facilities is particularly important, as such linkages provide low-cost flexibility to an inflexible transit route, thus increasing the door-to-door competitiveness of transit (Bowden, Campbell, and Newman 1980). The other low-cost method is the European "Woonerf" treatment of high density residential streets, which allows complete car access, but, by careful landscaping and provision of angle parking, narrows and winds streets to give greater priority to pedestrians and bicyclists (van Vliet 1983).

**Planned congestion.** "Woonerf" is also labeled planned congestion, as it involves placing a limit on private vehicle movement and adjusting priorities to give advantage to other transportation modes. It also involves the acceptance of limits on the provision of parking (as recently announced in Chicago) and the level of road availability; it shifts the orientation from road construction to traffic system management (Organization for Economic Cooperation and Development 1973, 1978). Planned congestion should reduce environmental impact from large highways in urban areas. It does require accepting lower average traffic speeds and favoring accessibility over mobility. That these techniques are likely to save gasoline is strongly indicated by the data in this study. But, as with reurbanization, there are many other sides to this policy.

Many observers will say that a policy accepting congestion denies fundamental rights. Others have suggested that far from being an economic disincentive, "automobile restraint" can be a tool to improve a city's "viability as a business centre" (Small 1985); that a less car-dependent transportation system is far

more equitable, especially for the young (Schaeffer and Sclar 1975); and that cities limiting auto use provide the opportunity for a more convivial, community-oriented urban society (Illich 1973). At the least, we can say that the transition to a lower gasoline-using city need not be painful if the perceived problems from congestion are consistently being offset by real gains in access through new transit systems and new, more centrally located housing.

## Conclusion

This study suggests that physical planning agencies have a major contribution to make in the conservation of transportation energy in cities. Policies that relate to prices, income, and vehicle efficiency as generated by econometricians undoubtedly have their role, but without direction in land use and commitment of transportation resources to nonautomobile modes, these policies will not be sufficient. The data in this study suggest that there is a large potential for conserving gasoline in U.S. cities by shifting to land use and transportation patterns that are evident in other cities around the world and also within some U.S. cities. The more precise data that are now available through this study provide perspective for physical planners in establishing achievable goals. The policies of reurbanization and reorientation of transportation priorities outlined here should reduce gasoline use, and may also provide economic, social, and environmental benefits. Indeed, one could argue that reducing dependence on gasoline and the automobile in general is a significant element in the present thrust for "the return of the livable city" in the United States (McNulty et al. 1986).

## Authors' note

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## Notes

1. The data for the correlations mentioned come from: income—U.S. Department of Transportation, (1985a); gasoline price—American Petroleum Institute (1980); size (area)—Bureau of the Census (1984).
2. Los Angeles is a little higher in its outer area density, probably because of the definition of the city that was used. Los Angeles is defined as the Los Angeles/Long Beach SMSA (L.A. County), which is not the full functional urban region embracing a number of other smaller SMSAs. This definition had to be used because of the difficulties in compiling such an array of data across so many separate administrative areas. Were the true urban region to be used, as is the case in the Tristate area of New York, then outer area densities could be expected to be lower, although not by much.
3. Data sources were: price—United Nations (1981) (data for

Sweden, Singapore, Hong Kong, and Moscow were obtained directly from the cities); income—Summers, Heston (1984); vehicle efficiency—Chandler (1985), Energy and Environmental Analysis Inc. (1982), U.S. Department of Transportation (1985b), Transport Canada (1984).

4. The calculation method is described in the footnote to Table 4. Elasticities are derived from Pindyck (1979); Dahl (1982); Archibald and Gillingham (1981); and Wheaton (1982).
5. The hypothesis that it is primarily an Anglo-Saxon tradition to value rural "garden suburb" environments rather than compact urban environments is pursued by authors like A. D. King (on U.K. cities) and M. White and L. White and S. Grabow (on U.S. cities) and is reviewed in P. W. G. Newman and T. L. F. Hogan (1981).

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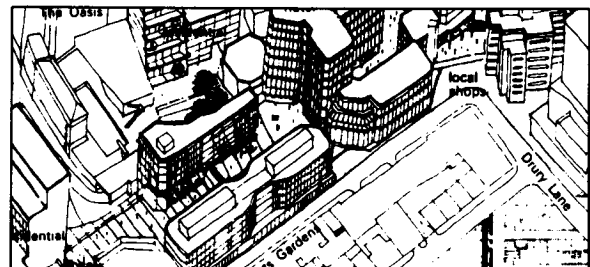
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