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ENERGY USE FOR BICYCLING

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ABSTRACT

Total energy use for bicycling — food, bicycle manufacture and sale, repairs and maintenance, tires, and bikeway construction — amounts to about 1,300 Btu/mile. The comparable figure for urban automobile travel is 11,000 Btu/passenger-mile for trips of five miles or less. Thus a shift from cars to bicycles would save about 10,000 Btu/passenger-mile, a 90% reduction from the energy use for automobiles. If 10% of the urban auto travel conducted during daylight and in good weather for trips of five miles or less was shifted to bicycles, the savings in 1971 would have been 180 trillion Btu, 1.8% of total urban automobile energy use.

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INTRODUCTION

This report estimates the energy requirements for bicycling. Energy uses considered include those to produce the additional food consumed by cyclists, to manufacture and sell bicycles and tires, to repair and maintain bicycles, and to construct bikeways. As part of these energy calculations, the dollar costs of cycling are also estimated. These energy and dollar costs are then compared with similar data for urban automobile travel. Finally, potential energy and dollar savings due to a shift of some urban auto travel to bicycles are estimated.

This study is motivated primarily by our present energy problems, particularly those that relate to the automobile and its gasoline consumption. A combination of oil scarcities, rising oil prices, increasing oil imports, and concern for the environmental impacts of oil production and automobile use suggests the need to improve the energy performance of automobiles. One possibility is to encourage the use of bicycles, rather than automobiles, for short urban trips. As shown below, the energy required per mile of bicycling is only a small fraction of that required per mile of auto travel. However, potential energy savings due to a shift from cars to bicycles are small relative to total national energy use, because bicycles are competitive with cars only for short trips.

Urban air pollution provides another incentive to examine the bicycle as a passenger transport mode, rather than as just a recreational vehicle. In response to the Federal Clean Air Amendments of 1970, states must submit to the U.S. Environmental Protection Agency plans for meeting air quality standards. Increased use of bicycles as a partial substitute for automobiles would help to meet these standards.

Finally, bicycle sales in the United States are booming, up from less than 4 million in 1960 to almost 14 million in 1972. Also, a much larger fraction of bicycles sold today are for adult use than was true in the past.

The energy and dollar figures for bicycling presented here are based on a number of estimates and personal opinions. Data concerning use of bicycles for transportation are not available, largely because such travel is currently only a small part of total urban passenger travel. Nevertheless, the results should be useful as first approximations to the energy and dollar costs of cycling.

TOTAL ENERGY USE FOR BICYCLES

Figure 1 and Table 1 present total energy use estimates per mile of bicycling. These numbers are derived by first estimating dollar costs for bicycles, repairs, maintenance, tires, and bikeways — all on a bicycle-mile (passenger-mile, PM) basis. These dollar costs are then multiplied by appropriate energy coefficients obtained from ref. 1. The methodology used to evaluate energy costs, applied to automobiles, is described in refs. 1-3.

The incremental human energy required for bicycling[4,5] at 10 mph is about 110 Btu/mile. This is the energy consumed in addition to that

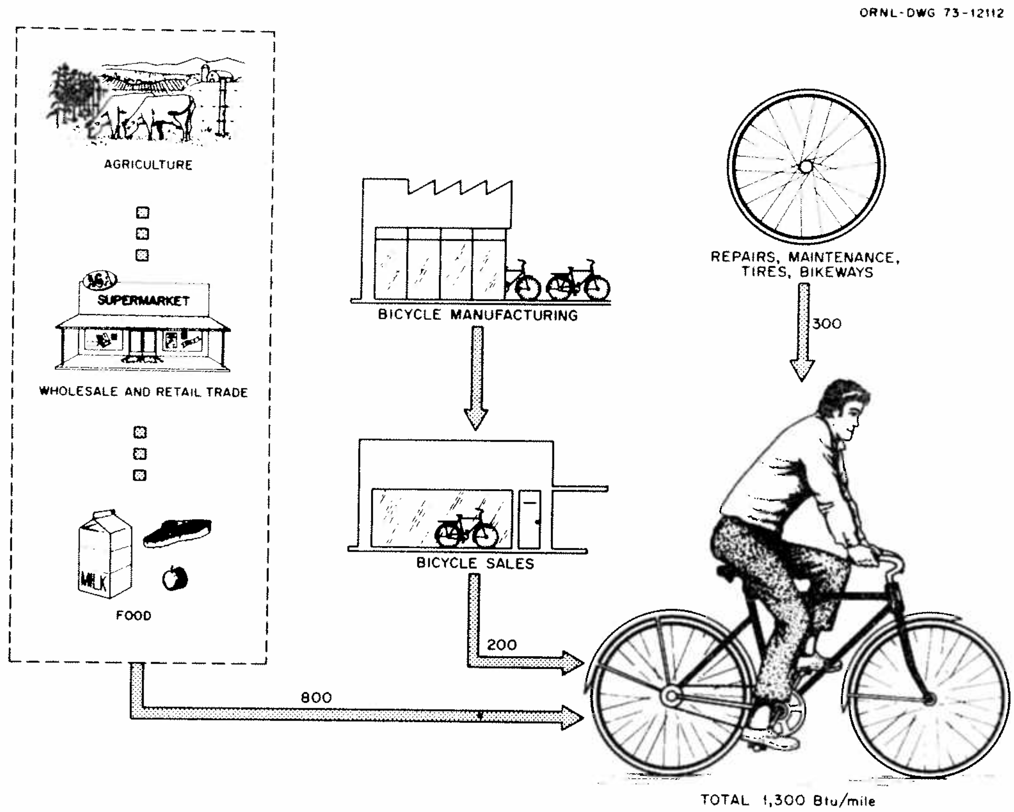

Fig. 1. Total energy requirements for bicycling, 1971.

Table 1. Estimated total energy use for bicycling, 1971

Function	Cost (¢/PM)[a]	Energy coefficient (Btu/$)	Energy use (Btu/PM)[a]
Food input	1.32	–	(110)
Energy for food	–	–	790
Bicycle			
manufacture	0.31	47,000	150
transport, sale	0.22	29,000	60
Repairs, maintenance	0.33	27,000	90
Tires	0.33	60,000	200
Bikeways	0.06	78,000	50
Totals	2.57		1,340

[a]PM = passenger-mile.

required for sedentary activities such as sitting, standing, or driving a car.*

In order to develop this human energy output, the cyclist consumes additional food. In 1971, about 7.2 Btu of primary energy (coal, oil, natural gas, falling water, uranium) were consumed to grow, process, transport, sell and prepare each Btu of food in the United States.[6] Thus the primary energy needed to provide food for a cyclist is 790 Btu/mile.

Per capita food expenditures in 1971 were $573. Food consumption[7] was 3,300 Calories/day (13,000 Btu/day) per capita. Thus food cost the consumer $120/million Btu; the additional food needed for cycling cost 1.32 cents/mile.†

We assume that the price of an average new bicycle in 1971 was $80. This represents roughly a 50-50 split between a good 3-speed and a moderately priced 10-speed.‡ About 60% of the purchaser's price for a new bicycle is due to manufacturing costs; the remainder is for transportation, wholesaling, and retail trade.[8] We assume a 10-year lifetime for

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*Bicycling requires a total human energy commitment of about 400 Calories/hr. Subtracting 120 Calories/hr for sedentary activities, dividing by 10 mph, and multiplying by 4 Btu/Calorie yields 110 Btu/mile.

†These dollar and energy figures assume that the kinds of additional food eaten by a cyclist are representative of a typical American diet. If the cyclist eats grain products and sweets to provide energy for cycling, then the dollar and energy costs would be much less than indicated in Table 1.

‡The 1971 and 1972 Sears and Montgomery Ward catalogs show a price range (including shipping charges) of $50 to $70 for 3-speed and $70 to $110 for 10-speed bicycles.

bicycles* and 1,500 miles of riding per year. The mileage figure assumes a 4-mile trip to work for 30 weeks/year plus 300 miles of recreational riding annually.

Bicycle repair and maintenance costs are taken as $5/year; we also assume that one tire will be replaced each year at $5/tire. These figures assume that the owner does minor repairs and that an adequate system of bikeways is available. Currently, cyclists ride in the gutter where glass and trash collect; this increases maintenance, repair, and tire costs.

Bikeway construction is estimated to cost $25,000 per mile for a two-lane bikeway.[9,10] Bikeway lifetime is taken as 20 years. Bikeway capacity is 5900 bicycles/hr for a two-lane bikeway.**

To estimate construction costs per mile of bicycle travel, we need an average "use factor" for bikeways (i.e., the fraction of capacity actually used). Reference 11 assumes that the average use factor for automobiles on new urban arterials is 6.6%. Studies in Denver[12] and Philadelphia[13] show that weather conditions are suitable for cycling 85% of the time. (These studies were made by bicycle enthusiasts and may be optimistic.) Federal Highway Adminstration data[14] show that 74% of all automobile travel is initiated between 7 AM and 6 PM (the daylight hours).

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*The question of bicycle theft is irrelevant here, because stolen bicycles can still be used.

**The moving cyclist requires an area 4-ft wide by about 18-ft long (6 ft for the bicycle plus 12-ft headway). Then capacity is

$$\frac{5280 \text{ ft/mile} \times 4 \text{ ft/lane}}{(4 \times 18)\text{ft}^2\text{/bicycle}} \times 10 \text{ mph} = 2930 \text{ bicycles/lane-hr} .$$

Accounting for bad weather and darkness reduces the assumed bikeway use factor to 4.2%. Then the cost of bikeways is 0.06 cents/mile of cycling.*

The costs discussed above are summarized in Table 1. Based on our estimates, bicycling costs 2.6 cents/mile, half of which is for food.

The rightmost column of Table 1 shows energy use estimates derived by multiplying dollar costs by energy coefficients obtained from ref. 1. The energy coefficients are for 1963; they are scaled from 1963 to 1971 by use of the ratios — total national energy use/GNP** — for the two years.[1,2] The Input/Output sectors used in ref. 1 do not coincide exactly with the bicycle expenditure categories used here: for example, the energy coefficient used for bicycle manufacturing comes from the I/O sector "Motorcycles, bicycles & parts." Thus, use of these energy coefficients introduces additional approximations and potential errors; see ref. 1 for a discussion of the limitations in using these coefficients. Total energy use for bicycling is estimated (Table 1 and Fig. 1) at 1,300 Btu/mile, equivalent to 100 miles/gal.

TOTAL ENERGY USE FOR AUTOMOBILES

Before we can compare the dollar, energy, and time tradeoffs between bicycles and automobiles, we review the relevant data on automobiles. The following is based primarily on results developed in ref. 3, applicable to 1971.

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*The cost of bikeways per mile of cycling is

$$\frac{\$25{,}000/20\ \text{years}}{(5860\ \text{bicycles/hr})(0.042)(8760\ \text{hr/year})} = 0.058\ \text{cents/mile}\ .$$

**65,900 Btu/$ in 1971 and 83,500 Btu/$ in 1963.

Table 2 summarizes total energy requirements for urban automobiles. The average car in 1971 traveled 11.9 miles/gal in urban driving. Including the indirect energy uses — petroleum refining, auto depreciation, oil, repairs, maintenance, parts, tires, insurance, parking, garaging, tolls, highway construction — increases auto energy use by nearly 70%. Put another way, gasoline consumption accounts for 60% of total energy use; inclusion of petroleum refining and transportation and sale of gasoline brings this figure up to 75%. Manufacture and sale of cars account for 8% and highway construction for another 7% of total energy use. Considering both direct and indirect energy uses, urban driving requires 19,000 Btu/vehicle-mile (VM).

Table 2. Total energy use for urban automobiles, 1971

Function	Cost (¢/VM)[a]	Energy coefficient (Btu/$)	Energy use (Btu/VM)[a]
Gasoline			
consumption	-	-	11,400
refining	0.9	0.208 Btu/Btu	2,400
transport, sale	1.1	37,000	400
Oil	0.2	-	100
Automobile			
manufacture	2.3	55,000	1,300
transport, sale	0.9	29,000	300
Repairs, maintenance, parts	1.7	27,000	400
Tires	0.5	60,000	300
Insurance	2.3	25,000	600
Parking, garaging, tolls	1.8	27,000	500
Taxes (highway construction)	1.6	78,000	1,300
Totals	13.3		19,000

[a]VM = vehicle-mile.

Source: ref. 3, using data from refs. 1, 15-18.

Table 3 provides a breakdown of total energy costs of urban auto travel as a function of trip length.[3] Unit energy consumption is high for short trips because of cold starts (ref. 17).* Total energy use for auto trips less than or equal to (≤) 5 miles averages 11,200 Btu/PM. From

Table 3. Total energy use for urban automobiles as a function of trip length, 1971

Trip length (miles)	Total energy use		Occupancy (PM/VM)[a]	Percent of urban auto[b]		
	(Btu/VM)[a]	(Btu/PM)[a]		VM	PM	Trips
1	27,300	14,400	1.9	3.3	3.3	26.1
2	23,000	11,500	2.0	5.5	5.7	14.6
3	21,500	11,400	1.9	6.0	5.9	10.8
4	20,400	10,700	1.9	5.3	5.3	6.9
5	19,800	9,900	2.0	8.5	9.0	9.0
6–10	18,600	9,800	1.9	28.0	27.6	18.2
11–15	17,800	9,400	1.9	22.5	22.2	8.9
16–20	17,100	9,000	1.9	16.5	16.3	4.7
21–30	16,500	7,900	2.1	4.4	4.7	0.8
Urban averages	19,000	9,900	1.9	100.0	100.0	100.0
Averages for trips ≤5 miles	21,700	11,200	1.9	28.6	29.2	67.4

[a]VM = vehicle-miles, PM = passenger-miles.

[b]In 1971, urban auto travel totaled 525 billion VM (55.0% of national auto travel), 1009 billion PM (49.0% of national auto travel), and 99 billion trips (92.4% of the national total), from ref. 18.

Sources: energy use from ref. 3; occupancy and distribution of auto travel from ref. 18.

*The results given in Table 3 assume that all work trips (about 1/3 of total auto mileage) and half of all other trips are started cold, i.e., 2/3 of all urban trips are with cars started cold and the remainder are started with fully warmed-up cars.

an energy standpoint, the bicycle (Table 1) is eight times as efficient as the typical urban automobile. The dollar cost of auto travel[3,15] for these short trips is 7.2 cents/PM, nearly triple the cost of bicycling.*

Table 4 provides data for urban auto commuting as a function of trip length. Occupancy for commuting is much lower than for the average auto trip[14,18] — 1.4 rather than 1.9 PM/VM. Also, all trips to work and back are assumed to be driven with cars started cold. Therefore, energy consumption for auto commuting is quite high; compare Tables 3 and 4. For

Table 4. Total energy use for urban commuting by auto, 1971

Trip length (miles)	Total energy use		Occupancy (PM/VM)[a]
	(Btu/VM)[a]	(Btu/PM)[a]	
1	34,100	24,400	1.4
2	26,100	18,600	1.4
3	23,700	18,200	1.3
4	22,400	17,200	1.3
5	21,400	15,300	1.4
6-10	19,600	14,000	1.4
11-15	18,600	13,300	1.4
16-20	17,900	11,900	1.5
21-30	17,200	10,100	1.7
Urban averages	19,800	13,900	1.4
Averages for trips ⩽5 miles	23,900	17,600	1.4

[a]VM = vehicle-miles, PM = passenger-miles.

Sources: energy use from ref. 3; occupancy from ref. 14.

*11.3 cents/VM exclusive of gasoline (Table 2) plus 2.4 cents/VM for gasoline (from ref. 3) because gasoline consumption for trips ⩽5 miles is 20% higher than the urban average; 13.7 cents/VM divided by 1.9 PM/VM yields 7.2 cents/PM.

trips ≤5 miles, a total of 17,600 Btu/PM are required. Thus bicycles are 13 times as energy-efficient as automobiles for urban commuting. The cost of commuting by car is about 10 cents/PM,* almost four times the cost of bicycling.

COMPARISON OF BICYCLES AND AUTOMOBILES

We compare bicycles and cars for urban trips ≤5 miles in terms of energy, money, and time. We exclude longer trips from consideration because the time difference between autos and bicycles for such trips is considerable.

We assume that the cyclist travels at an average speed of 10 mph, with a total delay time of five minutes for locking and unlocking the bicycle, etc. (Fig. 2). Data concerning automobile commuting[14,19] suggest a six minute delay time and an average driving speed of 20 mph.** The travel times shown in Fig. 2 are representative: delay times and speeds vary widely depending on the purpose of the trip, its location, and time of day.

The last column of Table 5 shows the time saved or lost as a function of trip length due to a shift from cars to bicycles, based on the results

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*13.7 cents/VM divided by 1.4 PM/VM yields 9.8 cents/PM. Commuting costs are actually higher because of poorer fuel economy due to cold-start.

**Commuting by car to downtown areas may take longer than indicated in Fig. 2. For example, a set of 10 races between bicycles and cars conducted in Washington, D.C. during an October 1973 morning rush hour yielded nine bicycle winners and one tie. Average door-to-door speeds for the cars were only 10 to 12 mph for these short trips.

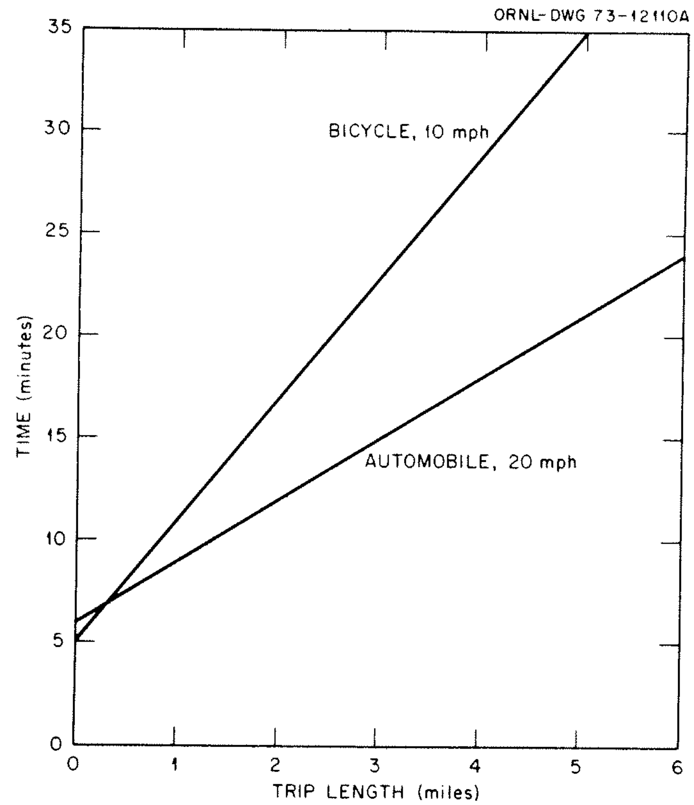

Fig. 2. Travel times as a function of trip length for bicycles and automobiles.

Table 5. Savings due to a shift from automobiles to bicycles for short urban trips

Trip length (miles)	Energy (Btu/trip)		Money[a] (cents/trip)		Time (minutes/trip)
	Average	Commuting	Average	Commuting	
1	13,000	23,000	5	7	-1
2	20,000	35,000	9	14	-5
3	30,000	51,000	14	22	-8
4	38,000	64,000	18	29	-11
5	43,000	70,000	23	36	-14
Averages					
Per mile	10,000	18,000	5	7	-2
Per trip[b]	24,000	41,000	11	17	-6

[a]Average money savings are 4.6 cents/mile for the average trip and 7.2 cents/mile for commuting.

[b]The average automobile trip length (for trips ≤5 miles) is 2.3 miles.

of Fig. 2. For trips shorter than one mile, the bicycle is faster; as trip length increases, the temporal advantage of cars grows rapidly. However, the average time penalty per trip is only six minutes.

Table 5 also shows energy and dollar savings due to the shift from cars to bicycles for both "average" urban trips and for commuting. Two cautionary notes concerning this table are needed. First, the savings include depreciation and other non-operating expenses such as insurance. If those who switch from cars to bicycles do not sell their cars, the actual energy and dollar savings will be less than given in Table 5 because the savings in Table 5 are obtained by apportioning all auto-related costs on a passenger-mile basis.

Second, the dollar and energy costs considered here include only those borne directly by cyclists and auto users. Various costs associated with street maintenance, traffic control, motor vehicle code enforcement, and junk-car disposal are not covered by prices paid by auto users. In addition, environmental costs associated with cars such as air and noise pollution, congestion, and resource depletion are not paid for solely by auto users. Because these externalities are so much greater for the automobile than for the bicycle, including these costs in the energy and dollar calculations would increase the differences in costs between cars and bicycles.

Table 5 and Fig. 3 show that the energy saved in switching from autos to bicycles is considerable, ranging from 85% for a five-mile average trip to 95% for a one-mile commute. The savings for a 2.3-mile trip are 24,000 Btu for the average journey (an 88% reduction), and 41,000 Btu for a commute (a 93% reduction). The money savings for these trips are 11 and 17 cents, respectively.

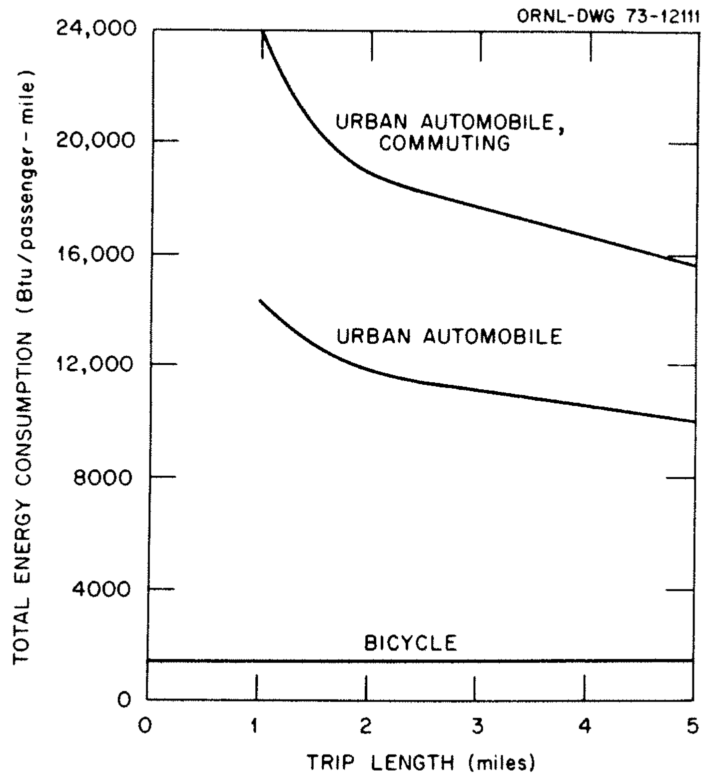

Fig. 3. Total energy requirements per PM for bicycles and automobiles.

From the point of view of the traveler, the dollar savings due to a shift to bicycles must be balanced against the lost time. If a traveler values his free time at more than $1.10/hr, then it may not be in his self-interest to shift to bicycles, given the results of Table 5. For commuting trips, the break-even point is $1.70/hr.* Money, however, does not tell the whole story. People also consider other factors such as safety, health, exercise, and traffic congestion.**

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*As a comparison, reducing auto speeds from 70 to 55 mph is economically justified only if highway travelers value their time at less than 50 cents/hr.

**For example, if 15 minutes of bicycling a day is viewed as recreation and/or desirable exercise, then the bicycle has a decided temporal advantage (and even greater monetary and energy advantages) over the automobile.

We can now estimate total potential energy savings due to a large-scale shift from cars to bicycles for these short urban trips. Auto travel for trips ≤5 miles totaled 295 billion PM in 1971 (Table 3).[18,20] Roughly 63% of this travel occurred under weather and lighting conditions suitable for cycling (85% × 74%).[12,13] If half of this auto travel (equal to 9% of total urban auto PM) had shifted to bicycles, the total energy savings in 1971 would have been 920 trillion Btu (160 million barrels of oil), 9% of total urban passenger transport energy use.* The dollar savings of such a shift would have been $4 billion.

If we consider the gasoline savings alone (i.e., exclude indirect energy uses), 650 trillion Btu (120 million barrels of oil) would have been saved in 1971,** 7% of total automobile gasoline use that year.

It seems unlikely that as much as 50% of short auto trips could be readily shifted to bicycles. Unfortunately, there are insufficient data to develop accurate estimates on the likely shift. However, a number of recent surveys suggest that people will use bicycles if it is safe to do so. A Philadelphia survey found that 24% of auto commuters to downtown would commute by bicycle.[13] Nearly 40% of the respondents in a Denver survey said they would ride bicycles (for transportation or recreation or both).[12]

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*Total potential energy savings for 1971: $(\underset{\text{auto}}{11{,}200} - \underset{\text{bicycle}}{1{,}300})\,\text{Btu/PM} \times \underset{\text{travel} \leq 5\ \text{miles}}{295\ \text{billion PM}} \times \underset{\text{daylight}}{(0.74)} \times \underset{\text{weather}}{(0.85)} \times (0.50) = 920$ trillion Btu .

**Potential gasoline savings for 1971: 7,000 Btu/PM × 295 billion PM × (0.74)(0.85)(0.50) = 650 trillion Btu .

The experience in Davis, California, suggests that the shift to bicycles has reduced auto travel by at least 10%.[21] Members of the Los Angeles League of American Wheelmen use their bicycles for a variety of purposes: 87% for recreation, 49% for commuting to work, 49% for shopping, and 31% for commuting to school.[10]

From these surveys and data, we hypothesize a 10% shift from cars to bicycles for short urban trips during good weather and daylight (a 1.8% shift in urban auto traffic). This assumes that 90% of the people making such trips would not use bicycles because of bad weather, bicycle safety, an aversion to exercise, poor health, importance of time, or just because they dislike cycling. The total energy savings in 1971 would have been 180 trillion Btu (30 million barrels of oil). By comparison, oil imports in 1971 totaled almost 1,400 million barrels.

Shifting some urban traffic from autos to bicycles would save both energy and money with only minor time losses. Energy savings might run as high as 30 million barrels of oil yearly, because the bicycle is so much more energy-efficient than the auto. However, relative to total oil use or oil imports, the savings are small.

CONCLUSIONS

This study examined total energy requirements for bicycling and compared these figures with figures for urban automobile travel. Typically, the energy savings due to a switch from cars to bicycles is 10,000 Btu/passenger-mile, a 90% reduction. If 10% of the auto travel conducted during daylight and in good weather for trips $\leq$5 miles was shifted to bicycles, the savings in 1971 would have been 180 trillion Btu, 1.8% of total urban automobile energy use. In absolute terms, this potential energy saving is large — worth more than $0.6 billion; but relative to total energy use, the saving is small.

A number of assumptions and approximations were used to derive the numbers upon which these results are based:

1. Many of the dollar figures associated with bicycling are based on personal experience, not on statistical evidence.
2. The energy coefficients are approximate; see ref. 1.
3. The analysis of total energy costs for automobiles contains numerous approximations; see ref. 3.
4. The energy and dollar savings calculated are "average" in that all costs — operating and fixed — are apportioned on a PM basis.
5. The calculated dollar and energy costs ignore externalities and are therefore too low; this is especially true for the automobile.

In addition to the issues of energy, money, and time considered here, other factors are influential in determining whether or not people will use bicycles for transportation. Additional potential benefits of cycling include reduced urban parking problems, reduced air and noise pollution, improved health for cyclists, greater mobility for cyclists, the possibility of combining recreation, exercise, and transportation in the same trips, and an increase in urban transportation options.* Offsetting these benefits are the problems associated with personal safety, bicycle security, exposure of cyclists to auto exhaust, inability to carry heavy loads on bicycles, and the need for reasonably good health to cycle.

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*This is particularly important for poor, but healthy, people who have limited access to cars.

To a large extent, the first three problems can be alleviated by public policies designed to encourage safe use of bicycles. An important element of such a policy is the construction and maintenance of bikeways and bike parking facilities.* Educating motorists and bicyclists concerning safety is another way to reduce the dangers of bicycling. In addition, policies which seek to internalize externalities associated with the automobile will increase the costs of owning and operating cars. Such changes include higher tolls, increased parking charges, higher gasoline taxes, and annual license fees that are related to auto fuel use. Increasing the costs of using cars in cities will encourage the shift to bicycles, a less expensive form of travel.

Finally, education concerning the full costs and benefits of auto and bicycle travel might increase public awareness and acceptance of bicycling.

Greater use of bicycles could save energy. Other energy conserving measures include use of small motorcycles rather than cars for urban travel, greater use of mass transit, shift from average cars to subcompacts, and increased auto load factors.

Small motorcycles travel about 100 mpg; this implies a total energy cost of 2,600 Btu/PM — double that for bicycles and one-fourth that for cars. While bicycles are more energy-efficient, motorcycles have a much greater energy conservation potential: because of their higher speed,

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*Based on the numbers developed here, an annual bicycle license fee of $1 (or a new bike excise tax of $10) would provide sufficient funds to construct bikeways and bike-lock facilities.

they can successfully compete with cars over the complete range of urban trip lengths. A 10% shift from cars to small motorcycles for urban travel would, in 1971, have saved 740 trillion Btu, four times as much as the bicycle savings.

A 10% shift from average to subcompact cars for urban travel would have saved 260 trillion Btu in 1971, 40% more than the bicycle savings.[3] Increasing auto load factors by 10% would have cut energy use by 900 trillion Btu, saving five times as much energy as the bicycle would have.[3]

These examples are not meant to deprecate the usefulness of bicycles for urban transportation; they are intended to give some perspective on the bicycle's energy implications. While the quantities of energy saved by a shift to bicycles are not trivial, they are smaller than those resulting from adoption of other measures. However, these measures are not mutually exclusive. For example, a shift from cars to bicycles for short trips plus increased load factors on remaining auto trips would save more energy than either measure alone.

Our nation currently faces severe problems associated with the use of oil. Shifting some traffic from cars to bicycles will not solve these problems; however, such a shift will help reduce our dependence on petroleum and probably have a number of other beneficial side effects.

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