Where We Are, Where We're Going 2

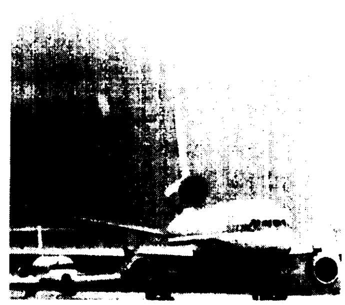
This section describes the current status of the U.S. transportation system and, in so doing, illuminates the "targets" for energy conservation. Although statistics are used extensively, the reader should note that transportation data are often of relatively poor quality (see box 2-A)_.

A SNAPSHOT OF THE U.S. TRANSPORTATION SYSTEM

Figure 2-1 provides a broad overview of where energy is being used in U.S. transportation. As shown, light-duty vehicles—automobiles, pickup trucks, utility vehicles, and vans—account for more than half of all U.S. transportation energy use. They are used predominantly for passenger travel. Airplanes, also used predominantly for passenger travel, account for 14 percent of U.S. transport energy use. These two components of passenger travel thus represent a tempting target for energy conservation measures.

Freight trucks are the second largest user of transportation energy, accounting for nearly 23 percent of total U.S. use. Freight truck energy use, expected to grow substantially during the next two decades, should thus also be an important focus of attention for energy conservation. Although other freight modes—pipelines, shipping, and rail (most of rail energy is freight energy)—are important (and rail could attract freight from trucking, with subsequent energy savings), they are clearly of lesser significance than trucks for national energy savings.

The transportation system in the United States provides U.S. residents with the highest level of personal mobility—in terms of vehicle trips made and miles traveled—in the world. The United States has the world's highest number of automobiles per capita



BOX 2-A: Transportation Data and Precision

Data on transportation passenger- and vehicle-miles traveled and energy consumed often are imprecise and apparently contradictory Part of the problem involves differences in assumed boundaries and definitions Do vmt data for light trucks include all trucks less than 10,000 pounds gross vehicle weight, all trucks judged to be driven for personal use, or all 2-axle 4-tire trucks? Do estimates of energy consumption for air travel Include fuel purchased by international earners in this country and then consumed outside of our boundaries? How are the various urban boundaries--central business district, central city, urban area, suburbs—defined? Where do government and military vehicles fit in? Alternative data sources use different definitions and boundaries and many do not specify precisely what these are Problems created by different definitions and boundaries virtually explode when International comparisons are made, because practices in other countries may be radically different from U S norms

A second problem concerns data collection Critical transportation data often are obtained by extrapolating from limited samples (e g household and mileage data) National data are aggregated from State data that may not be collected in a uniform manner (e g vmt data sources range from limited survey instruments to odometer readings from annual vehicle Inspections) Fuel use often is estimated by adjusting gasoline sales data, but there are startling differences among areas in the percentage of purchased fuel actually consumed within each area's boundaries

The result of these problems is that estimates for Important transportation variables may differ substantially among different sources For example measures of energy use in air transport vary significantly between values used by the Energy Information Administration (EIA) in its "Annual Energy Outlook" and those found in Oak Ridge National Laboratory's "Transportation Energy Data Book " The EIA value is *3.21* quads for 19901, the Oak Ridge value is about **2.55** quads for 1989.[2] Since air travel's energy use has recently (1982-89) been Increasing at an annual rate of 44 percent,[3] the Oak Ridge value adjusted for a year's growth is 266 quads—more than half a quad less than the EIA value Both estimates include military air travel and both Include purchases of domestic fuel by International earners, and there is no apparent discrepancy in definitions or boundaries

Discrepancies such as these can cause major analytical problems, particularly when values sought are the differences between two data points that do not come from the same source When seeking the difference between two variables of similar magnitude, relatively small discrepancies in the variables can yield huge errors in the resulting difference For example, if the result sought is (A-B) where the estimate for A is 200 and the estimate for B is 1.80 a 5 percent uncertainty in A yields a range for (A-B) of O 10-030, that is (A-B) could be off by as much as 200 percent

SOURCE Office of **Technology** Assessment 1994

[1] Energy Information Administration *1992 Annual Energy Outlook* DOE EIA-0383(92) (Washington, DC January 1992) table Al 4

[2] S C Davis and M D Morris *Transportation Energy Data Book* ed 12 OR NL-671 O (Oak Ridge TN Oak Ridge National Laboratory March 1992) table 27

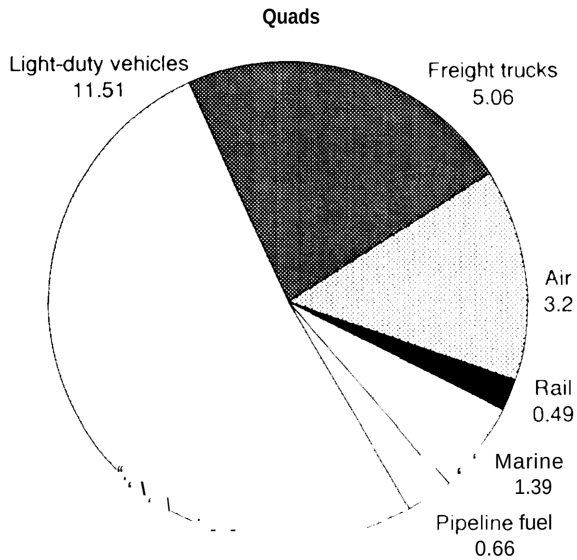
[3] Ibid table 210

—0.575 in 1989.[1] In 1990, the United States had a total population of 250 million, 167 million licensed drivers, and 179 million vehicles operating—1.07 *vehicles per licensed driver, or 1.92 vehicles per household.*[2] The average adult with a driver's license travels 30 miles per day of local, personal travel, and even adults without licenses manage to travel 10 miles a day.[3] In 1990, the average U.S. resident traveled about 13,500 miles—compared with about 7,800 miles for the average Frenchman or 6,400 miles for the average Japanese.[4]

The overall U.S. transportation system is the largest user of oil in the U.S. economy and is itself almost totally dependent on oil. In 1990, 63.6 percent of all U.S. oil use went directly to transportation,[5] and much of the remaining oil use (e.g., residual oil) was in byproducts of transportation fuel production. In the same year, the system was 97.1 percent dependent on oil as a fuel and lubricant.[6] Consequently, the U.S. oil import problem is primarily a *transportation* problem.

The large quantity of oil, and of energy per se, consumed by U.S. transport may pose a problem for its global warming potential as well. The United States is responsible for about 24 percent of current world emissions of carbon dioxide from fossil fuel combustion,[7] and the transportation sector emits 22 percent of U.S. fossil fuel carbon dioxide (almost 30 percent if the entire fuel cycle is considered).[8] As transportation energy use grows, so will its contribution to worldwide emissions of greenhouse gases.

FIGURE 2-1: U.S. Transportation Energy Use in 1990



SOURCE Energy Information Administration

Passenger Travel

U.S. passenger travel is dominated by the automobile and the highway system. In 1990, about 86 percent of passenger-miles were auto (and personal light truck) miles, and about 10 of the remaining

[1] S.C. Davis and M.D. Morris, *Transportation Energy Data Book*, ed. 12, ORNL-6710 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1992), table 1.3.

[2] Ibid., table 4.1. Note that "vehicles" includes trucks and buses.

[3] A T Reno, "Personal Mobility in the United States," Transportation Research Board, Special Report 220, 1988.

[4] Data for 1990 obtained from L. Schipper and N. Kiang, International Energy Studies, Lawrence Berkeley Laboratory, in advance of publication in the *Transportation Energy Data Book*, ed. 14 (Oak Ridge, TN: Oak Ridge National Laboratory, forthcoming). The Japanese data are for 1989.

[5] Davis and Morris, op. cit., footnote 1. Statistical Summary.

[6] Ibid.

[7] U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC U.S. Government Printing Office, February 1991), figure 3-3.

[8] S.C. Davis and S.G. Strang, *Transportation Energy Data Book*, ed. 13, ORNL-6743 (Oak Ridge, TN Oak Ridge National Laboratory, March 1993), table 3.49.

14 percent were air miles. Buses and trains accounted for only 4 percent of passenger-miles, versus 15 **to 20** percent in Europe and 38 percent in Japan.[9] Autos and light trucks used for passenger travel accounted for more than 50 percent of all transportation energy use in 1990,[10] and 70 percent of all highway energy use.[11] This dominance is not surprising given a series of U.S. policies strongly favoring the automobile and automobile-oriented development:

- low gasoline taxes that allow U.S. gas prices to stay at about one-third those of most Organization for Economic Cooperation and Development (OECD) nations;
- low taxes on autos (average 5 percent in 1992);
- treatment of free employee parking as a normal business cost and a tax-free benefit to employees (and the widespread availability of free parking as a result);
- tax subsidy of homeowner mortgages, promoting single-family home development and sprawl;
- payment of many highway transportation services from general funds rather than gasoline taxes; and
- remarkably easy availability of driver's licenses.[12]

The U.S. highway system consists of about 3,800,000 miles of roadway, including 44,000 miles in the Interstate System,[13] 260,000 miles in the Federal-Aid Primary System,[14] 400,000 miles in the Federal-Aid Secondary System,[15] 125,000 miles in the Federal-Aid Urban System,[16] 2,751,000 miles of local roads,[17] and 226,000 miles of Federal roads in national forests and parks and on military and Indian reservations.[18] The system also includes nearly 577,000 bridges. Virtually every local jurisdiction has a large backlog of road and bridge maintenance and repair needs: more than 10 percent of the Nation's roads have enough potholes, cracks, ragged shoulders, ruts, and washboard ridges to be classified as deficient; and nearly 42 percent of the Nation's bridges are rated as unable to handle traffic demand or structurally deficient.[19] In the Nation's largest cities, the result of the poor state of repair of the road system coupled with inadequate peak capacity results in several billion dollars in congestion costs each year.[20]

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[9] Schipper and Kiang, op. cit., footnote 4.

[10] U.S. Department Of Energy, Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383 Washington, DC: January 1993), table A. 14. Note that definitions of total transportation energy use can differ and thus change the percentages of different sectors. For example, the Oak Ridge *Transportation Energy Data Book* defines "transportation energy use " in two different ways—with or without off-road heavy-duty use for construction and farming, and military travel—and thus reports 1990 transportation energy as 23.2 and 21.8 quadrillion Btu (quads), respectively.

[11] Ibid.

[12] J. Pucher, "Urban Travel Behavior as the Outcome of Public Policy: The Example of Modal-Split in Western Europe and North America," *Journal of the American Planning Association,* autumn 1988, pp. 509-520.

[13] Routes that connect Principal metropolitan areas, serve the national defense, or connect with routes of continental importance in Mexico or Canada.

[14] Interconnecting roads important to interstate, statewide, and regional travel.

[15] Major rural collectors that assemble traffic and feed to the arterials.

[16] Urban arterial and collector routes, excluding urban extensions of the major primary arterials.

[17] Residential and local streets.

[18] U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management, and Finance*, OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991), based on U.S. Department of Transportation data.

[19] Ibid.

[20] Ibid. Congestion cost is the estimated cost of travel delay, excess fuel consumed, and higher insurance premiums paid by residents of large, congested urban areas. The magnitude of these costs is controversial.

TABLE 2-1: Mass Transit Active Vehicle Fleet and Infrastructure

Vehicles	
Buses	52,945
Vans for service to senior citizens and people with disabilities (not public)	20970
Subway cars	10325
Rural service vehicles (primarily vans—public)	10101
Commuter rail cars	4646
Vans	2412
Streetcars and cablecars	940
Commuter rail locomotives	472
Others (including ferryboats)	372
Total	103,183
Infrastructure	
Miles of commuter rail track	4830
Miles of rapid rail transit track	1 744
Commuter rail stations	958
Rapid rail transit stations	911
Miles of light rail track	687
Bus light maintenance facilities	523
Demand response service maintenance facilities	86
Rapid rail transit maintenance facilities	43
Commuter rail light rail maintenance facilities	35
Light rail light maintenance facilities	18
Ferryboat light maintenance facilities	4

SOURCE U S Department of Transportation Federal Transit Administration *Public Transportation in the L/n/fed States Performance and Condition* Report to Congress (Washington, DC June 1992) table 12 p 18

The U.S. transit system consists of an array of regional and municipal systems, including buses. light rail, commuter rail, trolleys, and subways, as well as an array of vehicles providing "paratransit" services--dial-a-ride, van pools, subsidized taxis, and shared rides in minibuses or vans. The basic characteristics of U.S. mass transit are presented in table **2-1.** Most cities of 20,000 or more population have bus systems, usually operated by a municipal transit authority. In fact, buses on established routes with set schedules account for more than one-half of all public transit passenger trips, U.S. transit operations are heavily subsidized, with subsidies paying for about 57 percent of operating costs in 1990[21]**—probably** the highest cost-per-ride subsidy level among OECD nations.[22]

Although most cities have some kind of transit system, most mass transit in the United States is concentrated in a relatively few cities. In 1991.71 percent of all transit trips were in the 10 cities with rapid rail systems: New York City, Boston, Philadelphia, San Francisco, Chicago, Washington, DC, Cleveland, Atlanta, Baltimore, and Miami.[23] In fact. in 1990, 35 percent of transit passengers and 41 percent of transit passenger-miles were in New York City and its suburbs.[24]

[21] Federal Transit Administration, *Public Transportation in the United States: Performance and Condition* (Washington, DC: U.S. Department of Transportation, June 1992).

[22] Pucher, op. cit., footnote 12. In 1982, the Netherlands, Belgium, and Italy paid a higher *share* of total costs than the United States, but their cost per ride was much lower.

[23] Federal Transit Administration, op. cit., footnote 21.

[24] Ibid.

The road system in U.S. cities is shaped largely by the need to offer capacity to satisfy peak traffic periods. Traditionally, the peaks largely consisted of worktrips, and these still dominate, although not as much as before (in metropolitan areas, worktrips constitute 37 percent of all person trips in the two peak periods from **6** to **9** a.m. and 4 to 7 p.m.[25]). The commute represents 26 percent of the total household vehicle trips and 20 percent of the household person trips.[26] A key characteristic of U.S. commuting patterns is that worktrips generally are relatively short and diffuse in both origin and destination. The mean worktrip is slightly less than 10 miles long and takes 20 minutes; more than half are under 6 miles; and less than 4 percent are more than 30 miles.[27] And although the pattern of workers living in surrounding areas and commuting to the central business district (CBD) may once have been true, in 1980 the CBDs employed only 9 percent of the workers in their total urban areas and 3 percent of workers living outside the central city. Data for the average urban area in 1980 illustrate the diffusion of worktrips: 37 percent of the workforce lived and worked in the central city, 36 percent lived and worked in fringe areas outside the central city, and the remaining 27 percent commuted between central city and fringe (in both directions) .28 This is not a commuting pattern that can be well served by transit, or by walking or biking. In fact autos accounted for more than 90 percent of commuting trips in 1990-a dominance that has been stable for 20 years .29

As noted above, the diverse commuting patterns of most U.S. cities are not easily served by mass transit, which depends on large numbers of travelers having common origin and destination. Aside from *patterns*, transit also requires *density* of origins and destinations. With a few conspicuous exceptions (e.g., New York City), U.S. cities have extremely low residential densities, fewer than eight persons per acre compared with European urban densities 2 to 3 times as high and Asian densities 10 times higher.[30] Further, U.S. cities are far less centralized than European cities, and they do not tend to mix residential and commercial development (which might promote walking and bicycling). Instead, a combination of forces and circumstances—taxation and other policies discussed above, massive roadbuilding, strong consumer preferences for single-family homes, high incomes, and the relatively young age of American cities (most either were developed after the beginning of the automobile era or experienced much of their growth during this era)—have yielded a U.S. urban development pattern characterized by:

> [an] undifferentiated mixture of land uses and a broad plateau of population density . . . other central places scattered over the urban landscape challenge the primacy of the historic CBD.[31]

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25 H.W. Richardson and P. Gordon, "New Data and Old Models in Urban Economics," University of Southern California, preliminary draft, December 1992, table 3. The precise character of changes in trip purposes is made uncertain by the manner in which trip purpose data are collected. A worktrip interrupted by a stop to run an errand would be counted as a shorter worktrip plus another trip. Because trip "chaining" of this sort has increased, some of the shift away from worktrips may be an artifact of the data rather than an actual shift.

26 Davis and Morris, op. cit., footnote 1, tables 4.9 and 4.10. The vehicle load factor for commutes is Only 1.2, versus 1.6 for all trips.

27 I.S. Lowry, "planning for Urban Sprawl," *A Lwk Ahead--Year* 2020, Transportation Research Board, Special Report 220, 1988. This pattern of commuting breaks down only in the extremes of urban development-in very small towns where workers may 1ive quite far away, and in large cities of more than 1.25 million people where the sheer size of the area, and the difficulty of optimizing location because so many households have twu or more workers, cause average worktrips to be longer.

28 Ibid.

29 Davis and Morris, op. cit., footnote 1, table 4.11.

30 P.G. Newman and J.R. Kenworthy, *Cities and Automobile Dependence: A Sourcebook* (Aldershot, England: Gower Publishing Co., 1989).

31 Lowry, op. cit., footnote 27.

In other words, central business districts in most American cities have neither the preponderance of jobs nor the proximity of residential areas. Residences are now primarily in the suburbs, and to a large extent, a significant portion of the business community has followed, to gain access to suburban labor and (for shipping operations and manufacturing) to interurban transportation.[32] Many of these businesses have coalesced into subcenters. This produces a complex and multidirectional travel pattern.

The result is that in 1990 transit carried a mere 5.5 percent of urban commutes, with an additional 3.1 percent walking or bicycling.[33] For overall national travel in 1989, buses (excluding school buses) accounted for only about 45 billion passenger-miles, and trains for only about 26 billion passenger-miles—1.4 and 0.8 percent, respectively,[34] of a total of more than 3 trillion passenger-miles for all vehicular modes.

Estimating or comparing the energy intensities of different passenger travel modes is confusing and often controversial because much of the collected data are not specific about trip purposes for each mode, and the different modes often compete with each other only (or primarily) for specific types of trips. Also, the energy intensity of the vehicles tells a limited story, since a great deal of energy is embedded in each mode's capital infrastructure and expended in ancillary activities such as powering stations, repairing roadways and guideways, and so forth. Further, national averages hide large variations from city to city, because average auto travel speeds vary greatly among cities, and the service and physical characteristics of public transport systems (especially rail) vary greatly as well. In the following discussion, only vehicular energy use is considered, and the focus is on national averages.

In city travel, the energy efficiency of different passenger travel modes has tended to converge somewhat over the past few decades, as auto travel has grown more efficient and public transportation has declined in efficiency. When the same types of trips are compared, however, transit probably still retains an edge.[35] In highway or intercity travel, bus transit, at least, remains substantially superior to auto. In 1989, the fuel intensity of private autos was 6,095 Btus per vehicle-mile[36] (about 20.3 mpg[37]), or 4,063 Btus per passenger-mile (p-m) when the load factor of about 1.5 passengers per auto is accounted for. The intensity of personal light trucks was about 6,605 Btu/p-m in 1989. For city travel, the intensity of autos was about 4,510 Btu/p-m, and of light trucks, about 7,340 Btu./p-m.[38] For worktrips, however, the intensity is higher—about 6,150 and 9,340 Btu/p-m, respectively (given a load factor of 1.1). For highway travel, auto intensity was about 3,470 Btu/p-m, and light truck intensity about 5,650

[32] Richardson and Gordon, op. cit., footnote 25.

[33] Davis and Morris, op. cit., footnote 1, table 3.16.

[34] Ibid., table 2.12.

[35] However appropriate comparison of the energy intensities of competing modes requires sophisticated evaluation of specific trips. As discussed in the section on public transportation in ch. 4, these comparisons should account for a variety of factors, including trip circuity, travel conditions, and traveler characteristics.

[36] Davis and Morris, op. cit., footnote 1. table 2.12.

[37] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1991*, DOE/EIA-0384(91) (Washington, DC: June 1992), table 23.

[38] If city fuel economy is about 90 percent of the combined highway-city value. This fraction holds fairly well for new car and light truck EPA fuel economy values. after adjusting for the different factors applied to city and combined fuel economy (0.90 and 0.85, respectively) to estimate on-road fuel economy. Based on Heavenrich et al., "Light-Duty Automotive Technology and Fuel Economy Trends Through 1991," EPA AA CTAB 91-02 (Ann Arbor, MI U.S. Environmental Protection Agency, May 1991), table 1. A possible flaw in this estimate is that it does not account for differences in load factor for city and highway travel; presumably, highway load factor will be higher.

Btu/p-m.[39] For long trips with higher load factors, however, the intensity is lower-perhaps 2,480 for autos (by assuming 2.1 persons per auto).[40]

For comparison's sake, the fuel intensity of transit buses was about 3,711 Btu/p-m, 82 percent of city auto intensity and 66 percent of city auto worktrip intensity; the intensity of intercity buses was 963 Btu/p-m, only 28 percent of highway auto intensity and perhaps 38 percent of intercity auto intensity. Rail systems exhibit similar energy relationships for city travel, but show much less gain when shifting to intercity travel. Transit and commuter rail had energy intensities of 3,397 and 3,102 Btu/p-m, 75 and 69 percent of city auto intensity, and 60 and 55 percent of city auto worktrip intensity, respectively. Intercity rail intensity was 2,731 Btu/p-m, 79 percent of highway auto intensity and 110 percent of intercity auto intensity. Air passenger travel, comparable with high-load-factor auto highway travel and intercity bus and rail, had an energy intensity of *4,796* Btu/p-m.[41]

Although automobiles continue to dominate U.S. travel, they face severe competition from commercial aircraft for trips of a few hundred miles and longer. As noted earlier, air transportation captures about 10 percent of the total passenger-miles traveled—447 billion passenger-miles for commercial aviation plus 12 billion in general aviation, in 1989[42]-—and is the most rapidly growing segment of the U.S. transportation system. In the 1980s air passenger-miles grew at a rate of more than 7 percent per year.[43] Air transportation accounts for about 12.5 percent of total passenger travel energy use, or 1.74 quadrillion Btu (quads) .44

The U.S. air travel system is extremely centralized, with most trips starting and finishing at relatively few major airports. In fact, the 10 largest airports serve 40 percent of all passenger trips, primarily because of widespread use by major air carriers of "hub-and-spoke" routes;[45] the top 100 handle 95 percent of all passenger trips. There are, however, more than 17,000 airports in the United States, most being public-use general aviation airports owned by municipalities, counties, or private groups, and used primarily by personal and business aircraft.[46]

The major airports experience substantial capacity problems and resulting delays, which waste significant amounts of fuel by idling aircraft on the runways and keeping arriving planes in holding patterns. Of the 25 airports with the most delays, Chicago's O'Hare ranks first, with total delays exceeding 100,000 hours per year; two airports have annual delays between 75,000 and 100,000 hours; two more have delays between 50,000 and 75,000 hours; and the remainder are between 20,000 and 50,000 hours.[47] If no capacity improvements are made or peak shaving measures taken, the Federal Aviation Administration

[39] If highway fuel economy is about 117 percent of the combined highway-city value. This fraction holds fairly well for new car and light truck EPA fuel economy values, after adjusting for the differential factors applied to highway and combined fuel economy (0.78 and 0.85, respectively) to estimate on-road fuel economy (based on Heavenrich et al., op. cit., footnote 38, table 1). As before, no account was taken of possible differences in load factor between city and highway travel.

[40] Davis and Morris, op. cit., footnote 1, table 4.10.

[41] For auto trips comparable with competing air trips, however, load factor was likely higher than the 1.5 assumed for the auto intensity estimates.

[42] Davis and Morris, op. cit., footnote 1, table 6.2.

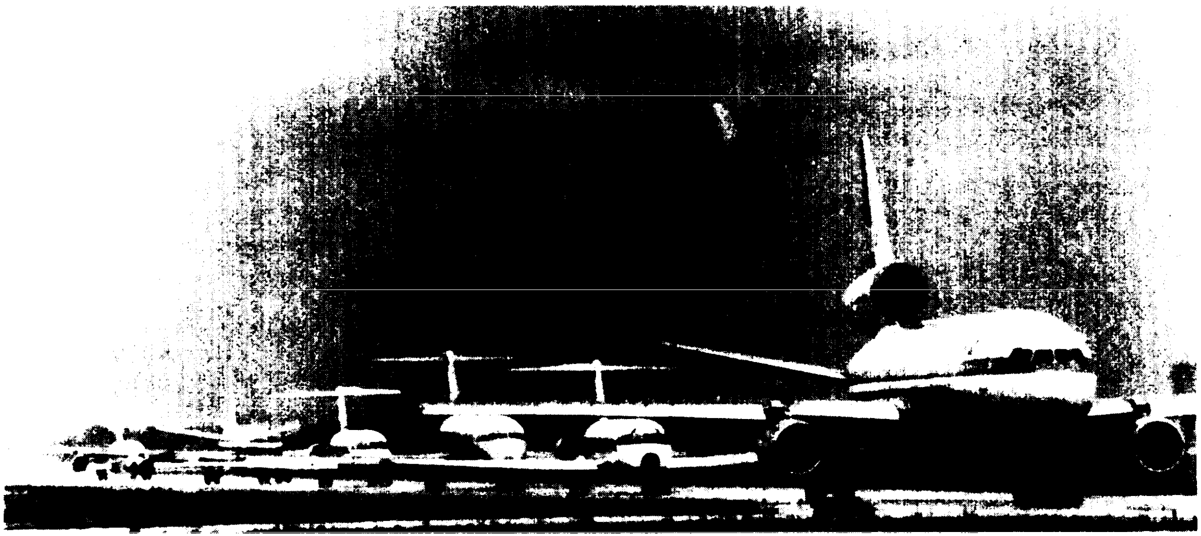
[43] Ibid.

[44] Ibid., table 2.12.

[45] J.F. Hornbeck, *Transportation Infrastructure: Economic and Policy Issues*, 92-158E (Washington, DC: Congressional Research Service, Feb. 11, 1992).

[46] Office of Technology Assessment, op. cit., footnote 7.

[47] Ibid.



Major airports experience substantial capacity problems and resulting delays, which waste significant amounts of fuel by idling aircraft on the runway and keeping arriving planes in holding patterns

expects 17 airports to move into the 75,000 -hour-and-up delay category by 1997.48

Freight Transport

The movement of freight—including everything from basic materials such as coal and grain to final consumer products such as clothing and computers-consumes about 6 quads of energy per year, accounting for about 17 percent of total U.S. oil consumption.[49] The freight system moves about 3.2 trillion ton-miles of freight per year. Trains and trucks each carry about 30 percent of this, barges about 24 percent, oil pipelines 16 percent, and air less than 1 percent. Energy use for freight shows a very different pattern than ton-miles. **Trucks dominate freight transport energy use, accounting for more than 80 percent of the total.** Trains and barges are far behind, accounting for 7 and 6 percent, respectively, of freight transport energy use (table 2-2).

Truck Freight

For nonbulk cargo-mail, perishable food, packaged goods, and so forth-trucks are the dominant transport mode. In 1989, trucks transported about 30 percent of cargo (table 2-2). In contrast, European freight shippers used trucks for about 64 percent of their shipping requirements, primarily because European countries do not produce or ship volumes of bulk goods comparable with the United States.

Trucks carry a wide range of goods .50 The cargoes carried by light (less than 5-ton) trucks differ significantly from those carried by heavy (greater than 13-ton) trucks. Almost one-third of light truck miles (excluding passenger only) are for the movement of craftsman's equipment; no other single cargo accounts for more than 10 percent of light truck miles. **Light trucks** (excluding passenger only) **account for 40 percent of total**

48 Ibid.

49 Davis and Strang, op. cit., footnote 8, p. 2-7; also table 2-2.

50 A more detailed discussion of the trucking industry can be found in U.S. Congress, Office of Technology Assessment, *Gearing Up for Safety*, OTA-SET-382 (Washington, DC: U.S. Government Printing Office, September 1988), p. 34.

TABLE 2-2: The U.S. Freight Transport System, 1989

	Energy use (percent)	Ton-miles (percent)	Expenditures (percent)	Energy Btu/ton-mile	Intensity index[a]
Train	7	30	10	427	**1 0**
Freight truck	83	29	83	4,924	115
Water (domestic)	6	24	2	403	0 9
Air cargo	1	<1	3	9,548	224
Oil pipelines	3	16	3	274	0 6
Total	**5.9 quads**		**$311 billion**		

[a] Intensities are simply energy use divided by ton-males Because cargo carried by the various modes may be very different, intensities are not, by themselves accurate indicators of energy efficiency

NOTE Data are uncertain Excludes light passenger-only trucks, natural gas and water pipelines, and International movements

SOURCE Office of Technology Assessment, 1994

freight truck energy use (table 2-3). These trucks are typically used for short-distance urban or suburban delivery. The technologies and policies affecting the energy efficiency of these trucks are quite similar to those for automobiles. For example, most new light trucks are required to meet Federal fuel efficiency standards.

Significant loads for heavy trucks, in contrast, include mixed cargo. processed food, and building material. The heaviest class of trucks, with a (gross vehicle) weight of more than 13 tons, accounts for over half of truck energy use (table 2-3). Most of these trucks are the familiar 18-wheel tractor-trailers with a capacity of 40 tons, and typically are driven many miles per year (heavy trucks driven more than 75,000 miles per year account for more than half of all heavy truck-miles).[51] Most are powered by diesel engines, typically large (greater than 800-cubic-inch displacement and 300 horsepower), 6-cylinder units.

TABLE 2-3: Current Truck Fleet, 1987

	Light	Medium	Heavy
Number of units (1 ,000)	11,760	1,700	1 820
Energy use (percent of total)	40	9	51
Average miles per gallon	148	7 4	5 5
Significant cargo	Craftsmen's equipment	Mixed cargo, processed food	Mixed cargo, processed food, building materials

NOTE Excludes trucks used for personal transportation Light - < 10000 pounds, Medium - 10000 to 26000 pounds, Heavy -26,000- pound

SOURCES U S Department of Commerce Bureau of the Census, *Truck Inventory arm Use Survey,* TC87-T-52 (Washington DC August 1990), and Office of Technology Assessment estimates

[51] U.S. Department of Commerce, Bureau of the Census, *Truck Inventory and Use Survey*, TC87-T-52 (Washington, DC: August 1990), pp. 102-106.

The penetration of energy-efficient technologies into today's heavy truck fleet varies.[52] Some technologies, such as demand-actuated cooling fans and air deflectors, are found in almost all units. Other technologies, such as trip recorders and auxiliary cab heaters (to eliminate engine idling), have achieved relatively low penetration—less than 25 percent. Trucking firms have paid increased attention to improving driver behavior in recent years. Some firms have instituted programs to reward drivers for energy efficiency, for example, offering prizes to drivers achieving the highest miles per gallon.[53]

Rail Freight

The freight railroad industry is dominated by 13 large Class 1 companies, which collectively account for more than 90 percent of railroad freight revenue.[54] These companies are regulated by the Interstate Commerce Commission (ICC), and extensive data on their operations and performance are available. The total revenue of these Class 1 firms in 1991 was $28 billion, Energy accounted for 7 percent of total operating expenses.[55]

The railway network consists of 117,000 miles of track.[56] This figure has been dropping steadily, as little-used tracks are abandoned or sold to non-Class 1 railroads. In comparison, there are more than 1.7 million miles of heavy-duty (i.e. appropriate for use by trucks) roads in the United States.[57]

Today rolling stock consists of 18,300 operating locomotives, all of which are diesel-electric, and about 1.2 million freight cars. Locomotives are typically rebuilt many times and therefore have very long lives—about one-third of today's fleet was built before 1970.[58] The relatively slow turnover of both locomotives and freight cars has slowed the penetration of energy-efficient technologies into the railroad system. For example, although since 1985 most new locomotives have microprocessor controls, improved wheel slip detectors, and other energy-efficient technologies, they represent only about 4 percent of the operating fleet.[59] Retrofit technologies have achieved higher penetration-flange lubricators, for example. are used by most train companies. Operational improvements such as improved dispatching, pacing, and reduced idling are also becoming more common.[60]

Coal accounts for the bulk of train movements—at 41 percent of total train tonnage. Other significant train movements include farm products (10 percent), chemicals and chemical products (9 percent), and nonmetallic minerals (7 percent).[61] An increasing fraction of train movement

[52] This discussion draws from Abacus Technology Corp., "Rail vs. Truck Fuel Efficiency," report prepared for the Federal Railroad Administration, April 1991, pp. 2-6 to 2-9 and 3-6 to 3-8.

[53] For a discussion of these programs, see "Driving for Fuel Economy," *Commercial Carrier Journal*, April 1993, pp. 67-70.

[54] Data in this paragraph are from Association of American Railroads, *Railroad Facts 1992* (Washington, DC: September 1992), pp. 3, 11.

[55] Interstate Commerce Commission, Office of Economics, *Transport Statistics of the United States* (Washington, DC: 1991, pp. 9-10; includes depreciation expenses.

[56] This includes only track owned by Class 1 railroads and excludes yards, sidings, and parallel lines. Association of American Railroads, op. cit., footnote 54, p. 44.

[57] This excludes unpaved roads and roads with less than 1 inch of pavement. U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1991*, FHWA-PL-92-025 (Washington, DC: 1992), p. 123.

[58] Association of American Railroads, op. cit., footnote 54, p. 45.

[59] Abacus Technology Corp., op. cit., footnote 52, pp. 2-3, 3-1.

[60] Ibid.

[61] Association of American Railroads, op. cit., footnote 54, p. 29. Data are tons loaded, not ton-miles. Data on ton-miles are not available.

is in the form of trailers or containers (i.e., intermodal shipments, using both train and another mode), typically carrying manufactured or intermediate goods.[62]

Waterborne Freight[63]

The water transport system consists of the inland waterways, coastal routes, and international (oceangoing) routes; the system includes about 200 major ports, each handling at least 250,000 tons of cargo annually or having channels deeper than 20 feet.[64] Many of the ports have linkages with truck, rail, and pipeline operations to provide integrated freight transport service. Although deep-water service is critical to handling international cargo operations, barges and tows carrying bulk commodities on the Nation's shallow draft (water depth less than 14 feet) inland and intracoastal waterway system are an important component of the U.S. freight transport system. The bulk of inland barge movements occurs on the Mississippi River, the Gulf Coast Intracoastal Waterways, and connected waterways. Other significant inland waterways include the Atlantic Waterway and the Columbia-Snake Rivers system.

Today's inland water vessel fleet consists of about 30,000 barges and 5,000 tugs. Most of these barges are built for dry cargo and can carry about 1,400 tons apiece. There are also tank barges, with an average capacity of about 2,700 tons per barge. The tugs include smaller workboats (typically 500 to 1,000 horsepower) used to maneuver barges near terminals, and larger line-haul boats (typically 1,500 to 10,000 horsepower) used for long-distance towing of barges.

Products carried by barges are quite similar to those carried by trains: coal accounts for the bulk of tonnage (30 percent), followed by petroleum products (19 percent), farm products (13 percent), and nonmetallic minerals and products (12 percent).[65]

Air Freight

Air movement of freight includes both "belly freight," which is cargo carried on passenger planes, and all-cargo aircraft. In general, only cargo with a very high time value (such as perishables, business documents, and specialized machinery) travels by air. Although air cargo movements have been growing very rapidly—almost 10 percent per year since 1980—they still account for only about 1 percent of freight transport energy use. Air cargo is very energy-intensive, requiring about twice the energy of trucks to move 1 ton 1 mile (table 2-2).

Pipelines

Pipelines carry virtually all the natural gas and water consumed in the United States, as well as about half of oil and oil product ton-miles.[66] In the case of natural gas, the only technical alternative to movement by pipeline is movement of liquefied natural gas (LNG) by tanker truck or train, which is technically feasible but often not cost-effective. Therefore, pipelines will continue to be the primary carrier of natural gas. Similarly, water will continue to move almost exclusively by pipeline due to the cost advantage. Oil, however, is moved by all modes; although in areas where pipelines already exist, they are often the least expensive (and most energy-efficient) mode.

TRENDS IN U.S. TRANSPORTATION

The previous section presents a snapshot of the U.S. transportation system. To examine the system further and take the first step in projecting its

62 Intermodal Association of North America, 1992 *Intermodal Index* (Riverdale, MD: December 1992).

63 This discussion draws primarily from the U.S. Army Corps of Engineers, *The 1992 Inland Waterways Review* (Ft. Belvoir, VA: October 1992), pp. ES-5, ES-7, 34-42.

64 Office of Technology Assessment, op. cit., footnote 7.

65 U.S. Army Corps of Engineers, op. cit., footnote 63, p. 4. Data are for 1990.

66 Eno Transportation Foundation, Inc., *Transportation in America, 9th* ed. (Waldorf, MD: 1991), p. 59.

future, recent trends in key transportation indicators are discussed briefly here.

The year 1973 was a key turning point for the U.S. transportation sector. Before 1973, transportation energy use rose strongly and steadily at about 4.5 percent annually, spurred by strong growth in travel demand and only modest changes in efficiency. The great increase in oil prices that began in 1973, coupled with expectations of very high future prices, changed the trend line dramatically: after 1973, growth in transportation energy use dropped sharply, averaging about 1.0 percent annually between 1973 and 1990.[67] Even so, transport energy use grew far more swiftly than other sectors of the economy, which either declined (industry) or were relatively stagnant (residential and commercial) after 1973 because of strong conservation efforts.

Passenger Travel

Passenger travel was not a primary cause of the growth in total transportation energy consumption during the 1973-87 period; its energy use grew only 9 percent during this time.[68] This slow growth was accomplished despite trends in personal vehicle occupancy, volume of passenger travel, and air travel that are clearly in an energy-intensive direction. For example, during the 1973-87 period, load factors for autos and light trucks declined from about 2.0 to 1.7, yielding a 15 percent drop in efficiency, all other things being equal.[69] This trend toward lower load factor was particularly pronounced in commuting; from 1980 through 1990 there was an extraordinary 35 percent increase in drivers traveling alone to work, from about 62 million to more than 84 million.[70] Although this rapid increase was due in part to an overall increase in employment. much of it was due to a shift away from carpooling. One clear reason for this trend was rising vehicle availability, as shown by the growing number of multivehicle households. The percentage of households with more than one vehicle has risen sharply over time. from 31 percent in 1969 to 57.9 percent in 1990.[71] In fact, the proportion of households with three or more vehicles rose from 4.6 percent in 1969 to 19.5 percent in 1990.[72]

From 1970 through 1987, the total volume of travel (in passenger-miles) increased by 2.27 percent per year—a higher growth rate than population.[73] As discussed in the next section, this growth reflects a number of changing demographic factors:

- an increased percentage of working-age persons (between 1980 and 1990, population increased 9.7 percent, while the working-age population increased 19.1 percent[74]);
- the rise in female workers:

[67] Davis and Morris, op. cit., footnote 1 table 2.6.

[68] L. Schipper et al., "United States Energy Use From 1973 to 1987: The Impacts of Improved Efficiency," draft, Feb. 14, 1990.

[69] Ibid.

[70] A.E. Pisarski, *New Perspectives in Commuting* (Washington, DC: Federal Highway Administration, July 1992).

[71] P.S. Hu and J. Young, *Summary of Travel Trends, 1990 Nationwide Personal Transportation Survey*, FHWA-PL-92-027 (Washington, DC: Federal Highway Administration, March 1992), table 4. The 1969 data do not include pickups or other light trucks as household vehicles.

[72] Ibid.

[73] L. Schipper et al., Lawrence Berkeley Laboratory, "Energy Use in Passenger Transport in OECD Countries: Changes Between 1970 and 1987," LBL-29830, 1991.

[74] Pisarski, op. cit., footnote 70.

- high rates of household formation (between 1980 and 1988, the number of households rose by 13.9 percent, population by 8.5 percent; [75]) and
- a large increase in the number of automobiles (from 89 million, or 0.44 per capita, in 1970 to 143 million, or 0.58 per capita, in 1987[76]).

This last factor—rising automobile ownership-is connected, at least in part, to the shifting form of U.S. cities, which have become increasingly dispersed over the past several decades. For the last 40 years, 86 percent of U.S. population growth has been suburban;[77] growth in rural and center-city areas has been slow, and many such areas have lost population. Similarly, job creation has been skewed to the suburbs: the percentage of all jobs located in suburban areas increased from one-third in 1960 to about one-half in 1980[78] and continues to grow. A recent examination of 12 major metropolitan areas shows a striking and consistent loss during the period 1982-87 of central-city job shares in all employment categories —manufacturing, retail, wholesale, and services—as well as employment growth rates increasing with distance from the central city in all sectors but manufacturing.[79] Thus, during the last 40 years, the character of U.S. cities changed markedly: from an employment and residential pattern focused on the central city and central business district, to a shift of population out of the central city and into the suburbs, and to the subsequent movement of employment to the suburbs in order to gain access to suburban labor and escape congestion, high land costs, high taxes, and declining services. Richardson and Gordon postulate that the current pattern of suburban businesses coalescing into subcenters may be only a waystation to an almost totally dispersed land use pattern, as telecommunications reduce the advantages of businesses grouping together even at the subcenter level.[80]

This shifting location of residences and jobs has changed the character of commuting. While overall rush-hour traffic has been growing because of disproportionate increases in the number of working-age adults, the *pattern* of commuting has shifted from the traditional suburban-to-city to a suburban-to-suburban commute. This shifting pattern is an important reason why, in the face of growing numbers of vehicles vying for basically the same road space and indications of increasing average worktrip lengths, average travel time to work has remained virtually unchanged (in two surveys of changes in commuting times between 1980 and 1990, one shows an increase, the other a decrease of less than a minute[81]).[82]

Finally, air travel, the most energy-intensive passenger travel mode, moved from a 4.6 percent share of passenger-miles in 1977 to 9.9 percent in 1987.[83] Passenger-miles have grown at a rapid rate over the past two decades, and the rate has accelerated slightly over time. From 1970 to 1989, the annual growth rate was 6.6 percent, with a 7.3

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75 J.F. Hornbeck, *Demographic Trends and Transportation Infrastructure*, 90-551 E (Washington, DC: Congressional Research Service, Nov. 28, 1990).

76 Davis and Morris, op. cit., footnote 1, tables 1.1, 1.3.

77 Hornbeck, op. cit., footnote 75.

78 Ibid.

79 P. Gordon and H.W. Richardson, University of Southern California, "L.A. Lost and Found," unpublished report, May 1992.

80 Richardson and Gordon, op. cit., footnote 25.

81 Pisarski, op. cit., footnote 70.

82 Two other factors are the sheer size of the commuting population (large time delays due to congestion—hundreds of millions of hours per year—could occur without substantially increasing the *average* commuting time) and a substantial excess capacity of roadway that needed to be worked off before significant congestion began.

83 Davis and Morris, op. cit., footnote 1, table 1.1.

percent rate for the period 1982-89.[84] The increase in actual energy use has been slower, however, because of increased energy efficiencies stemming from higher load factors, use of larger aircraft, gradually lengthening trips (the cruise portion of an aircraft trip is the most energy-efficient part), and improved technology. During 1970-89, the annual growth rate of energy use has been only 2.3 percent, less than half the growth rate of passenger-miles.

Most of the effect of the energy-intensifying changes in passenger travel was nullified by large increases in vehicle efficiency during the period 1973-87: the automobile fleet improved from about 13.3 to 19.2 mpg,[85] a 43 percent improvement in efficiency, and the entire light-duty fleet (autos and personal light trucks) improved from about 13.0 to 17.5 mpg, a 26 percent increase.[86] The lower figure for the light-duty fleet reflects the smaller increase in fuel efficiency of light trucks during this period as well as the growth in fleet penetration of these lower-efficiency vehicles.

Increasing the modal share of mass transit is a key component of most strategies to reduce transportation energy use and pollution. Past trends in transit usage are not, however, encouraging. In the 1950s and 1960s, transit ridership declined to less than half of pre-World War II levels; virtually no subsidies were available during this period, however.[87] Although subsidy levels increased 14-fold in the 1970s, there was little change in ridership. The number of workers who commute by transit actually *declined* between 1980 and 1990 by about 100,000 riders, or from 6.4 to 5.3 percent of all workers.[88] However, data from the American Public Transit Association for all trip purposes indicate a gradual *increase* in *unlinked* transit trips (a complete trip may include a few unlinked trip segments) from about 1975 to the present—from 7.3 billion to 9.1 billion trips,[89] an increase of about 1.6 percent a year.[90] According to the Nationwide Personal Transportation Survey, however, total transit person trips have been relatively stagnant over the past two decades, starting at about 4.9 billion in 1969, reaching a high of about 5.5 billion in 1983, and dropping again to 4.9 billion in 1990.[91]

Part of this stagnation in mass transit use undoubtedly is due to the sharp rise in multivehicle households, which discourages transit trips. Also, the number of households with no vehicles—prime transit candidates—has declined sharply, from nearly 13 million, or 20.6 percent, in 1969 to less than 9 million, or 9.2 percent, in 1990.[92] Pucher also attributes this stagnation to the funneling of most subsidy resources to expensive rapid rail systems, which created few new transit trips[93] and drew most of their ridership from buses.

[84] Ibid.

[85] Energy Information Administration, op. Cit., footnote 37.

[86] Schipper et al., op. cit., footnote 68.

[87] Pucher, op. cit., footnote 12.

[88] Pisarski, op. cit., footnote 70.

[89] American Public Transit Association, *1990 Transit Fact Book* (Washington, DC: September 1990), table 17.

[90] Unfortunately, interpreting this increase is difficult because nearly half of the added trips were on heavy rail systems. Many heavy rail trips generate home-to-station and work-to-station bus trips that are not independent transit trips but inflate the selected statistic: many of the new trips are probably statistical artifacts, i.e., transit users went from one long bus trip (one unlinked transit trip) to a short bus trip to the rail station and a long rail trip (two unlinked transit trips).

[91] Hu and Young, op. cit., footnote 71, table 16.

[92] Ibid., table 4.

[93] Pucher, op. cit., footnote 12.

Freight

Much transportation energy growth after 1973 was due to freight transport energy use, which increased 37 percent between 1973 and 1987; *passenger* energy use, as noted earlier, grew only 9 percent during this period. The growth in freight energy use was nearly **2.3** percent per year during this time, in contrast to a growth in freight *volume* of only 1.2 percent annually, much slower than the rate of economic growth.

Why did freight levels grow more slowly than the economy? First, the economy has gradually shifted away from basic materials and toward greater consumption of services and higher-value-added goods.[94] Although production of raw materials (such as coal and minerals) has increased, production of manufactured goods has grown much faster (table 2-4). And consumption of services—health, legal, amusement, education, and so on—has grown much more rapidly than consumption of goods. In 1970 goods accounted for 46 percent of the gross domestic product (GDP), while services accounted for 43 percent; in 1990 these numbers were 39 and51 percent, respectively.[95] This slowed freight tonnage growth, because services generate additions to gross national product (GNP) with fewer goods that require shipment; services also make use of higher-value-added goods that weigh far less per dollar of value than raw materials. Second, increased imports reduced freight because much of the U.S. market is close to the coasts and to ports of entry, thereby reducing *domestic* shipping distances.

TABLE 2-4: Changes in Production of Selected Materials and Goods (production index, 1970 = 1.00)

	1970	1990
Raw materials		
Coal production	100	1 55
Crude 011 production	100	076
Minlng	100	1 02
All crops	100	1 48
Primary metals	100	094
Manufactured goods		
Instruments	100	301
Electrical machinery	100	275
Rubber and plastic products	100	293

SOURCE U S Department of Commerce Bureau of the Census *Statistical Abstract of the United States* (Washington, D C 1992), pp 563, 657, 745

Changes in the nature of goods being shipped were reflected in changes in shipping modes. Over the last 20 years, movements by train and barge, which typically carry basic commodities (such as coal, farm products, and chemicals), grew slowly. Over the same period, truck and air freight movements, which carry greater value-added goods, grew more rapidly—in excess of GNP growth. Truck and air generally require more energy than trains and barges; therefore, these economic shifts have resulted in relatively rapid growth in freight transport energy use despite slow growth in total tonnage.

Other major trends have influenced the form and energy use of the freight transport system. Major Federal legislation was passed that partially deregulated portions of the system and generally encouraged competition. The Regional Rail Reorganization (1973) and Railroad Revitalization and Regulatory Reform (1976) Acts provided financial support for bankrupt train companies and relaxed some rate regulation by the Interstate Commerce Commission. The Staggers Act (1980) removed regulatory control of markets in which train companies faced substantial competition, and streamlined regulations relating to company mergers and track abandonment. The Motor Carrier Act of 1980 reduced restrictions on entry and expansion in the trucking industry and relaxed various regulations related to trucking. The Surface Transportation Assistance Act (1982) super-

[94] The shift to less material-intensive consumer goods is discussed in R. Williams et al., "Materials, Affluence, and Industrial Energy Use," *Annual Review of Energy*, vol. 12, 1987.

[95] The remainder was for structures. U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States* (Washington, DC: 1992), p. 430.

sealed certain State requirements on size and weight limits for trucks. These regulatory changes have resulted in greater competition, both within and among modes.

Another major influence on freight transport has been the growth of intermodal movements. Intermodalism usually refers to the carriage of trailers and containers by trains, with delivery to and from train terminals by truck, but can also refer to the use of barges or open ocean ships to transport containers, which are then moved by train or truck. Several innovative technologies have been implemented, including sealed containers that can be moved by train, barge, or truck; roadrailers (truck trailers that can ride directly on train tracks); piggybacking (putting truck trailers on railcars); and double-stack containers (putting two levels of truck-size containers onto railcars). Intermodal loadings on freight trains grew at an average annual rate of 4.9 percent from 1970 to 1990.[96] By 1991 their movements accounted for over 10 percent of all freight ton-miles.[97]

As noted above, freight energy use grew nearly twice as rapidly as freight volume. An important factor in the increase in freight energy use over the past few decades has been the rise in truck use (since trucks are second only to airfreight in energy intensity). From 1970 to 1990, heavy truck energy use rose at a 4.1 percent annual rate, or 125 percent for the period.[98] Heavy trucks began the period by accounting for 9.8 percent of total transportation energy, and ended it accounting for 15.6 percent.[99] Over these 20 years, there was only a modest improvement in truck fleet fuel economy (miles per gallon), with combination trucks improving from 4.8 to 5.5 mpg and larger single-unit trucks (with more than two axles or four tires) improving from 6.8 to 7.3 mpg. In addition, the fuel economy of automobiles increased more than three times as quickly as that of combination trucks during this period.[100]

Countervailing factors yielded small gains in truck fuel economy during the past two decades. Factors that contributed to improved fuel economy included technical improvements and increased trip lengths. Technologies implemented in recent years include electronic engine controls, demand-actuated cooling fans, intercoolers, aerodynamic improvements, low-profile radial tires, and multiple trailers. Market penetration of these technologies varies, although some, such as cab-top air deflectors, are found in almost all heavy trucks.[101] Increased average trip length—from 263 miles in 1970 to 389 miles in 1989—has also improved fuel economy due to the inherent efficiency advantage of longer trips.[102]

Factors hindering increased truck freight fuel economy included increased highway speeds,

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96 Loadings defined as the number of trailers and containers loaded on trains. Association of American Railroads, op. cit., footnote 54, p. 26.

97 Interstate Commerce Commission, office of Economics, *Transport Statistics in the United States—Railroads, Part 1* (Washington, DC 1991), p. 27.

98 Davis and Strang, op. cit., footnote 8, p. 2-18. Excludes 2-axle, 4-tire trucks.

99 Ibid.

100 That is 2.2 percent/yr versus 0.7 percent/yr, from Ibid., pp. 3-23, 3-42. Data are for fleet averages. Miles per gallon is not an ideal indicator of efficiency for trucks because it fails to reflect changes in truck size, loads earned, and other variables. Data on Btu per ton-mile, which do account for some of these variables, are scarce; however, existing data show much the same pattern as miles per gallon (I.c.. very slight improvement over the last 20 years).

101 Due in part t. these technical improvements, certain classes of trucks showed relatively rapid improvements in fuel efficiency. See, for example, Energy and Environmental Analysis, "Analysis of Heavy Duty Truck Fuel Efficiency to 200 1," report prepared for the U.S. Environmental Protection Agency, September 1991, p. 2-24.

102 Mileage data from Eno Transportation Foundation," Inc op. cit., footnote 66, p. 71. Much of the increase in trip length occurred from 1970 to 1980 and may have been due in part to shifts from trains; trip length increased little after 1980 due in part to the growth in intermodal freight movement.

changes in the truck fleets, and the long lives of truck engines. In general, higher speeds are less efficient due to greater wind resistance.[103] Average vehicle speed on both urban and rural roads has been steadily increasing.[104] Also, in 1987 States were allowed to increase speed limits to 65 mph on certain highways; since then, many States have done so. Over the last 20 years, larger trucks (which use more energy per mile, but less per ton-mile) have accounted for a growing fraction of the total truck fleet. And the average heavy truck engine is rebuilt several times (in contrast to automobile engines, which are rarely rebuilt) and may travel well over a million miles before being retired.[105] This leads to very slow penetration of new technologies that cannot easily be retrofit to existing engines. For example, less than 10 percent of the current truck fleet have electronic engine controls.[106]

While truck energy use was rising rapidly, rail energy use actually declined by 15 percent[107]--despite a 35 percent increase in ton-miles. Three key factors contributing to the gain in rail efficiency are:

1. Increase in average trip lengths—from 515 miles in 1970 to 751 miles in 1991.[108] Longer trips are more energy efficient due to fewer stops and greater sustained speeds.[109]
2. Operations and communications improvements. Improved routing, scheduling, and overall operations reduced empty car-miles, allowed for better matching of locomotives and loads, and minimized stops and starts.
3. Technical improvements, including reduced locomotive idling speeds, improved sizing of auxiliary loads, improved wheel-slip detection, greater use of flange lubricators, weight reduction, and aerodynamic improvements.[110]

In addition, the fraction of total railcars occupied by trailers and/or containers (i.e., intermodal shipments) has grown very rapidly since 1970, but it is not clear how this has affected the energy efficiency of the rail system.

During the period 1970-90, water-based freight transport had a moderate growth in ton-miles, much of it coming from increased movement of coal, farm products, and chemicals.[111] This mode also showed a small improvement in energy intensity: Btu per ton-mile improved at an average annual rate of 0.7 percent from 1970 to 1989. Both technical and operational factors contributed to this improvement:

- improved engines, with greater use of fuel management computer systems;
- improved matching of barges and tugs;
- improved operations aided by computers;

[103] For example, increasing speed from 55 to 70 mph more than doubles the power required.

[104] U.S. Department of Transportation, Research and Special Programs Administration, *National Transportation Statistics, Annual Report*, DOT-L 'N NTSC-RSPA-92-1 (Washington, DC June 1992), p. 62; U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1991*, FHWA-PL-92-025 (Washington, DC: 1992), p. 202.

[105] H. Sachs et al., *Heavy Truck Fuel Economy* (Washington, DC: American Council for an Energy-Efficient Economy, January 1992), p. 3.

[106] Based on a sample of medium- and heavy-duty truck fleets. Abacus Technology Corp., op. cit., footnote 52, p. 3-6.

[107] Davis and Strang, op. cit., footnote 8, p. 6-26.

[108] Association of American Railroads, op. cit., footnote 54, p. 36. One contribution to this increase was the closing of smaller and less utilized stations.

[109] With most longer trips, a smaller percentage of the trip will be under congested urban conditions that degrade energy efficiency.

[110] Abacus Technology Corp., op. cit., footnote 52, pp. 2.1-2.6

[111] U.S. Army Corps of Engineers, *The U.S. Waterway Transportation System: A Review* (Ft. Belvoir, VA: April 1989), p. 13.

- improved channels and locks; and
- use of larger barges and tugs.

Final] y, air freight has grown rapid] y during the past two decades, yet still accounts for a very small fraction of total freight ton-miles and total freight energy use. By one estimate, the energy efficiency of commercial aircraft (predominantly passenger transport, but including freight transport) has doubled since the early 1970s. Technical and operational factors contributing to this include improved aerodynamics. more efficient engines, and reduced aircraft weight.[112]

FORECASTING TRANSPORTATION ENERGY CONSUMPTION

Projections of future transportation energy consumption can play a powerful role in shaping policy by identifying emerging problems, pinpointing areas for energy savings, and providing a context within which to judge alternative policy options. For example, forecasts of continued rapid growth in travel demand, showing that reasonable levels of mobility cannot be maintained by "business as usual, " could provide an impetus for radical transportation policies that involve increasing urban residential densities and otherwise reversing the decline of central cities, On the other hand, forecasts that travel growth will slow drastically from previous levels would allow policymakers to proceed comfortably with technology-based solutions to urban congestion and pollution, and to avoid considering more drastic solutions.

This section examines the factors that will affect transportation energy consumption and describes some existing forecasts of transportation energy use. The basic focus is on energy use under normal market conditions (e.g., without major new government programs or changes in the underlying regulatory structure).

General Considerations—Factors That Will Affect Transportation Energy Consumption

Light-Duty Vehicles–Travel Demand

Both components of light-duty vehicle energy use—travel demand, measured as vehicle-miles traveled (vmt). and energy efficiency, meusured as vehicle fuel economy in miles per gallon-have grown robustly during the past 15 years, largely canceling each other out in terms of changes in overall fuel use. Over the next few decades, the rate of change of both factors is likely to decrease.

Light-duty vmt is widely expected to continue to rise. though not as rapidly as before. The rate of increase in light-duty passenger vmt between 1970 and 1990 was very large—about 3.3 percent per year. with auto travel growing at a somewhat slower rate (2.6 percent per year) and light truck travel growing at a much higher rate (6.9 percent per year).[113] (This represents all 2-axle, 4-tire trucks. not just trucks for personal use; for 1989, such trucks totaled 457 billion miles traveled, whereas personal trucks were only 290 bill ion miles.)[114] And the rate of increase in total light-duty travel became higher during 1982 -88—3.9 percent per year.

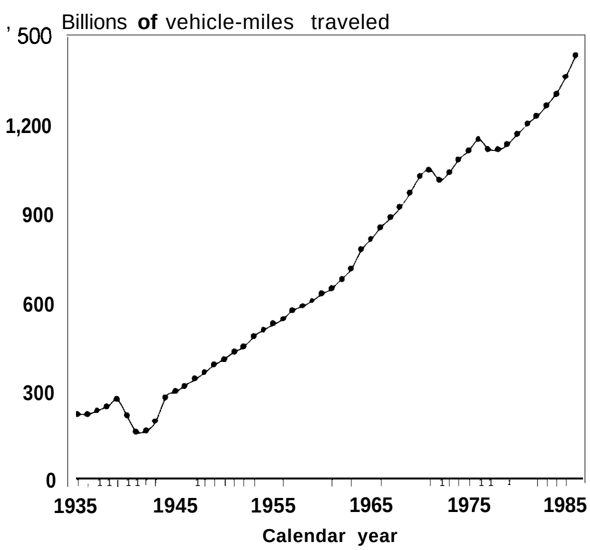
As shown in figure 2-2, the rise in vmt over the past several decades has been almost constant, because expected "saturation points" in auto ownership and travel demand did not occur. Initial assumptions that vehicle saturation would occur at one vehicle per household were surpassed in the United States in the 1930s. Then, a proposed satu-

[112] D. Greene, "Energy-Efficiency Improvement Potential of Commercial Aircraft," *Annual Review of Energy and the Environment*, vol. 17, 1992, pp. 537-573.

[113] Davis and Strang, op. cit., footnote 8, table 3.2.

[114] S.C. Davis and P.S. Hu, *Transportation Energy Data Book*, ed. 11, ORNL-6659 (Oak Ridge, TN: Oak Ridge National Laboratory, January 1991).

FIGURE 2-2: Growth in Passenger Auto Vehicle-Miles Traveled, 1936-89



SOURCE Office of Highway Information Management

ration point of one vehicle per worker was surpassed in the mid-1960s. Expected saturation of one vehicle for each licensed driver was surpassed in 1983.[115] And for the past 30 years, vmt per vehicle has remained at about 10,000 per year. driving total U.S. vmt upward at the rate of expansion of the fleet.[116] The year-by-year increase in travel faltered only twice, and then for very brief periods when gasoline supply problems were coupled with very sharp price increases.

More than half of the increase in vmt over the past 15 years can be attributed to an increase in the number of adults of driving age. The remainder was due to increased driving per licensed driver and a greater proportion of licensed drivers in the population (the latter due largely to the increased number of women in the workforce).

As noted, the future growth rate for vmt is widely expected to be lower—and possibly much lower—than the 3.3 percent per year rate of the 1970-90 period. Although the Office of Technology Assessment agrees that a decreased growth rate does appear to be likely, there is considerable room for argument about the extent and likelihood of the decrease. On the one hand, the stability of vehicle mileage trends in the past argues for caution in projecting a significant decrease; on the other hand, demographic factors do seem to argue for such a decrease. Some factors that will affect future vmt are discussed below.

Women in the workforce

During the past few decades, the growing share of women working, and therefore needing to commute, has contributed significantly to rising levels of light-duty vehicle travel. The percentage of adult working women rose from 37 in 1969, to 48 in 1983, and to 56 in 1990.[117] Of those working, the percentage with driver's licenses rose from 74 in 1969 to 91 in 1983. By 1990, women made up 46 percent of the total workforce, up from 27 percent in 1947.[118] Further increases in the share of women working will continue to affect the demand for transportation services during the next few decades, but probably at a slower rate because the current percentage of working women is high. However, fully 74 percent of adult males are employed,[119] compared with 56 percent of adult females. Although it is hard to foresee the proportion of women working soon reaching 74 percent, the gap in employment rates between men and women of 18 percent does indicate a potential for continuation of the past trend.

115 P.D. Patterson, "Analysis of Future Transportation Petroleum Demand and Efficiency Improvements," paper presented at the IEA Energy Demand Analysis Symposium, Paris, France, Oct. 12-14, 1987.

116 Ibid.

117 Hu and Young, op. cit., footnote 71, table 1.

118 C.A. Lave, "Future Growth of Auto Travel in the U. S.: A Non-problem," *Energy and Environment in the 21st Century*, paper presented at the Massachusetts Institute of Technology Conference, Mar. 26-28, 1990.

119 Hu and Young, op. cit., footnote 71, table 1.

The fact that women, working or not, still do not drive nearly as much as men (9,500 miles annually per licensed female versus 16,500 miles per year per licensed male[120]) appears to leave open the possibility that future shifts in lifestyles among women could drive vmt at a higher rate than predicted. However, a substantial part of the vmt gap between men and women appears to be caused by the social custom of men being the primary drivers for recreation, family, and social travel.[121] Were this custom to change. vmt would be redistributed but not increased. A further examination of the reasons for the vmt gap between men and women drivers would be useful in illuminating the potential for closing this gap. One interesting area for examination is that women incomes are still significantly lower than men's, and travel increases with income,[122] which implies that if women's incomes rise in comparison with men's, their travel will increase. Also, it is likely that a higher percentage of women than men work in nonspecialized service jobs relatively close to home, with correspondingly shorter commuting trip lengths. In 1990, women commuting in urban areas traveled an average of 8.35 miles in autos and 7.38 miles in passenger vans, versus 10.79 and 13.11 miles, respectively. for men.[123] Over time. if the status of women's jobs becomes closer to that of men, women commuting trips should grow longer.

Number of adults

The growth rate in adults of driving age will slow as the baby boom passes. After 2010, however. the rate of increase will depend on future birth rates, which are uncertain. A recent surge in birth rates points out the danger in assuming that trends will continue. Also, potential fluctuation in immigration rates introduces an important uncertainty.

To compare expected growth rates of driving-age adults with former rates of growth, the number of driving-age adults grew at 1.7 percent a year from 1970 to 1986, and the average 1988-2010 rate expected by the Bureau of Census is 0.7 percent per year.[124] *Given the importance of the increase in number of driving-age adults to past vmt increases, this expected decline in the growth rate of adult drivers is probably the largest single factor in predictions of lower vmt growth rates.*

The aging of the population has an effect on vmt as well. The ratio of young drivers to those of retirement age is expected to decline by 23 percent from 1991 to 2010,[125] yielding a 3 percent decline in vmt according to Energy Information Administration projections. However, it seems unlikely that drivers of retirement age in 2010 will exhibit the same travel behavior relative to younger drivers as today do because they will have grown up accustomed to high (auto) mobility; so this expected drag on vmt growth is probably overstated.

Vehicle load factor

A substantial portion of previous increases in vmt can be attributed to the increased number of households with multiple vehicles (in 1969, 31 percent of households had two or more autos; in

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[120] Ibid., table 17.

[121] Lave, op. cit., footnote 118.

[122] For example, for households with four or more members, annual vmt per household rises steadily with income, from 6,067 vmt for annual household incomes less than $10,000 to 23,879 vmt for incomes greater than $40,000. U.S. Department of Transportation, Federal Highway Administration, *1983-1984 National Personal Travel Survey, Volume 2, Personal Travel in the U.S.* (Washington, DC: November 1986).

[123] 1990 National Personal Transportation Survey data provided by Elaine Murakami, Federal Highway Administration.

[124] Reno, op. cit., footnote 3.

[125] U.S. Department of Commerce, Bureau of the Census, "Current Population Reports," Series P-25, No. 1018, *Projections of the Population of the United States, by Age, Sex, and Race: 1988 to 2080* (Washington, DC: January 1989), cited in U.S. Department of Energy, Energy Information Administration, *Assumptions for the Annual Energy Outlook 1993*, DOE/EIA-0527(93) (Washington, DC: January 1993).

1990, **58** percent did[126]) and the consequent decrease in trip sharing among household members. According to the National Personal Transportation Survey, the load factor for passenger cars was 1.9 in 1969 and 1.6 in 1990. Thus, the 1969-90 decrease in load factor by itself accounted for a 16 percent increase in vmt during this period. Although vehicle load factor could continue to decline, the rate of decline is likely to be less since the value cannot go below 1.0. This could slow the rate of vmt increase.

Availability of vehicles

Since the lack of access to a vehicle strongly constrains personal travel in most areas. vmt growth is fed by increases in vehicle availability. Because many adults own multiple vehicles, the near unit y of the ratio of personal vehicles to driving-age adults [127] does not imply that all driving-age adults have access to a vehicle; many adults remain whose personal vmt would increase if they obtained such access. Nevertheless, the fraction of potential drivers without access to vehicles is much smaller now than 20 years ago, and the potential for growth in vehicle access—and increased vmt from this growth-is thus much lower. Also, an unknown fraction of these "no-vehicle" adults cannot drive (because of illness or disability) or, perhaps because they live in high-density inner cities, have little need of a vehicle. On the other hand, although data are lacking, there likely are many vehicles whose condition does not allow them to provide a full measure of mobility to their owners; if these vehicles were replaced with newer, more reliable ones, the vmt of their owners might increase.

Possible driving time saturation among high-mileage drivers

Employed men between 25 and 54 years of age drive more than any other large group--about 18,000 miles per year. This represents an average of 1.5 hours per day spent driving. Although "common sense" about saturation of driving has been wrong before, it is at least possible that this group may be nearing saturation. One important area of uncertainty is whether a recent trend in auto design, making the vehicle interior a more hospitable environment (comfortable seating, excellent climate control, superb music systems, availability of telephone communication, etc.), will increase the likelihood of drivers' spending more time on the road. Another uncertainty is whether predicted increases in traffic congestion (see below) will outweigh possible continued increases in average (uncontested) speeds. If congestion finally begins to drive average speeds down, this will increase the amount of time required to drive a constant vmt. This implies that the already large amount of time spent on driving will have to increase just to maintain current levels of vmt and that large increases in vmt would put extraordinary time pressure on drivers. On the other hand, continued increases in average speeds will have the opposite effect.

Changing economic structure

The growth in part-time work and shift of the economy toward more services may lead to increased driving by bringing more individuals into the workplace and increasing delivery requirements. The potential for delivering certain types of services, especially information, electronically may eventually substitute for some transportation, but thus far such trends have not been observed.

Traffic congestion

The increasing congestion of metropolitan areas will alter travel patterns, Congestion will decrease the fuel efficiency of those trips that are made; discourage other trips (or shift them to public transportation or to the electronic media where pos-

126 Hu and Young, op. cit., footnote 71, table 5.

127 According to Lave (C. Lave, University of California, Irvine, "The Spread of the Automobile Demon: What Can We Do?" unpublished report, 1992), the ratio was 0.95 in 1989.

sible); encourage some people to work closer to home or move closer to work; and encourage businesses to move to the less congested fringes, increasing travel requirements. The net effect on fuel demand is unpredictable, although growing congestion is likely to act as a brake on vmt growth.

Development patterns

There is a strong correlation between vmt and development patterns, particularly urban density: residents of dense inner cores, for example, tend to drive and travel less than residents of low-density fringe areas. Although increasing traffic congestion might promote some movement of residences and businesses as noted above, few analysts expect important *national* changes in the current suburban pattern of U.S. development.[128] One important development pattern to watch is the potential for persons working in the suburbs to move into rural areas, with substantial increases in commute distances as well as longer trips to shopping and other services.

Conclusion

In OTA's judgment, the most predictable aspects of the above factors affecting future light-duty vmt are as follows: the lower number of persons reaching driving age (although high immigration rates could offset somewhat the passage of the baby boom), the likely slowdown of the effects of women entering the workforce and adults of driving age gaining new access to vehicles, the likelihood that vehicle load factor will not decrease as rapidly as it has in the past, and the continuing spread of suburban development. The first three factors act to slow vmt growth, although the effect of a slowdown in women entering the work force is uncertain; there is still room for the character of women's jobs to change substantially. with the potential for significant increases in the length of their commuting trips. The last factor will contribute to vmt growth. Claims that the number of vehicles per driving-age adult is close to saturation should be viewed with some skepticism in light of the fate of past claims of vehicle saturation and uncertainty about the ability of many registered vehicles to deliver full accessibility y to driving (especially given the aging of the fleet). Further, many determinants of transportation demand (e.g., gasoline prices, personal income, vehicle characteristics) are likely to change in hard-to-predict ways over the next few decades, and we do not fully understand how demand will respond to changes in these determinants.[129]

The uncertainty associated with the various factors affecting travel demand probably allows a range of feasible vmt growth rates of 1.5 to 3 percent, *without* considering the potential for future oil price shocks. An unexpected large increase in gasoline costs, or supply problems. could cause the growth in personal travel demand to fall below these levels or even to become negative for a time. A period of price stability and continuation of improvements in vehicle designs would make the high end of the range more plausible. Although OTA believes that this is a lower-probability outcome, the 3.3 percent increase in total vehicular traffic between July 1991 and July 1992,[130] which followed a year of vmt stagnation (perhaps recession-driven), forces caution in predicting that the long-term trend in vmt growth, which had been stable so long, will now turn downward.

Light Duty Vehicles—Fuel Economy

As discussed earlier, the fuel economy of the light-duty fleet has grown substantially, slowed only by a shift in consumer preference for light

[128] Reno, op. cit., footnote 3.

[129] E.L. Hillsman and F. Southworth, "Factors That May Influence Responses of the U.S. Transportation Sector to Policies for Reducing Greenhouse Gas Emissions," *Transportation Research Record No. 1267, Global Warming: Transportation and Energy Considerations 1990* (Washington, DC: Transportation Research Board, 1990).

[130] Federal Highway Administration, *Traffic Volume Trends, July 1992* (Washington, DC: U.S. Department of Transportation), data summary.

trucks, which are less fuel-efficient than automobiles. New auto fuel economy grew **5.3** percent annually from 1974 to 1988, from about 14 to 28 mpg (U.S. Environmental Protection Agency rating). New light-truck fuel economy grew more slowly, from 18.2 mpg in 1979 to 21.3 mpg in 1988.[131] The on-road fuel economy of the total fleet grew from 13.1 mpg in 1974 to about 18.4 mpg in 1988.[132]

As discussed in *Improving Automobile Fuel Economy: New Standards, New Approaches,*[133] future market-driven fuel economy is not likely to grow rapidly despite the continuing spread of technologies that could allow substantial improvements (see box 2-B for a brief description of the available technologies). The primary cause of reduced potential for rapid increases in fleet fuel

BOX 2-B: Fuel Economy Technologies for Light-Duty Vehicles

Weight reduction Includes three strategies—substitution of lighter-weight materials (e g , aluminum or plastic for steel), Improvement of packaging efficiency (i e , redesign of drivetrain or Interior to eliminate wasted space) and technological change that eliminates the need for certain types of equipment or reduces the size of equipment

Aerodynamic drag reduction primarily Involves reducing the drag coefficient by smoothing out the basic shape of the vehicle, raking the windshield, eliminating unnecessary protrusions, controlling airflow under the vehicle (and smoothing out the underside), reducing frontal area, and so forth

Front-wheel drive is now in wide use. Shifting from rear-to front-wheel drive allows mounting engines transversely reducing the length of the engine compartment, eliminating the transmission tunnel, which provides Important packaging efficiency gains in the passenger compartment, and eliminating the weight of the propeller shaft and rear differential and drive axle

Overhead cam (OHC) engines are more efficient than their predecessor pushrod (overhead valve, OHV) engines through their lower weight, higher output per unit displacement, lower engine friction, and improved placement of intake and exhaust ports

Four-valve-per-cylinder engines, by adding two extra valves to each cylinder, improve an engine's ability to feed air and fuel to the cylinder and discharge exhaust, increasing horsepower per unit displacement Higher fuel economy is achieved by downsizing the engine, the greater valve area also reduces pumping losses, and the more compact combustion chamber geometry and central spark plug location allow an increase in compression ratio

Intake valve control involves a shift from fixed-tnterval intake valve opening and closing to variable timing based on engine operating conditions, to yield improved air and fuel feed to cylinders and reduced pumping loss at low engine loads

Torque converter lockup eliminates losses due to slippage in the fluid coupling between engine and transmission

(continued)

[131] Davis and Hu, op. cit., footnote 114.

[132] Ibid., table 1.7.

[133] U.S. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New Standards, New Approaches*, OTA-E-504 (Washington, DC: U.S. Government Printing Office, October 1991).

BOX 2-B: Fuel Economy Technologies for Light-Duty Vehicle (cont'd.)

Accessory improvements Include adding a two-speed accessory drive to more closely match engine output to accessory power requirements plus design Improvements for power-steering pump alternator and water pump

Four- and five-speed automatic transmissions, and continuously variable transmissions by adding extra gears to the automatic transmission Increase fuel economy because engine efficiency drops off when the operating speed moves away from its optimum and the added gears allow the transmission to keep the engine closer to optimal speed

Electronic transmission controls to measure vehicle and engine speed and other operating conditions allow the transmission to optimize gear selection and timing, keeping the engine closer to optimal conditions (for either fuel economy or power) than is possible with hydraulic controls

Throttle body and multipoint fuel injection which are in wide use offer Improved control of the air-fuel mixture and allow the engine to continually adjust this mixture for changing engine conditions Multipoint also reduces fuel distribution problems

Roller cam followers by shifting to a rolling mechanism, reduce friction losses (Most current valve **lift** mechanisms are designed to slide along the camshaft)

Low-friction pistons and rings decrease friction losses by improving manufacturing control of tolerances reducing ring tension and improving piston skirt design

Improved tires and lubricants represent a continuation of longstanding t rends toward improved **oil** and tires with lower rolling resistance

Advanced engine friction reduction includes the use of Ilght-weight reciprocating components (titamum or ceramic valves composite connecting rods, aluminum lifters, composite fiber-renforced magnesium pistons) and improved manufacturing tolerances to allow better fit of moving parts

Electric power steering is used primarily for cars in the minicompact, subcompact and compact classes

Lean burn Improves an engine's thermodynamic efficiency and decreases pumping losses This requires a new generation of catalysts that can reduce nitrogen oxide in a "lean' environment

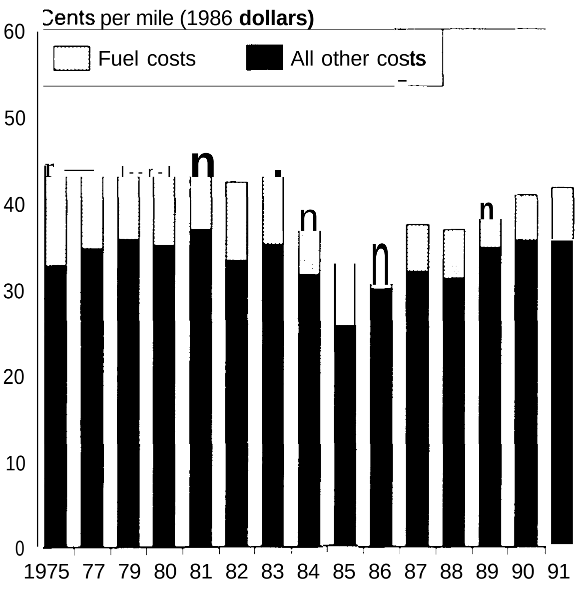
Two-stroke engines unlike conventional engines have a power stroke for every ascent and descent of the piston thus offering a significantly higher output per unit of engine displacement reduced pumping loss smooth operation and high torque at low speeds and allowing engine downsizing fewer cylinders (reduced friction losses) and significant weight reduction Also they operate very lean with substantial efficiency benefits (if nitrogen oxide problems are solved) Compliance with stringent emissions standards is unproven

Diesel engines (compression-ignition engines) are a proven technology and are significantly more efficient than gasoline two-valve engines even at constant performance new direct Inject Ion turbocharged diesels offer a large fuel savings Although the baseline gasoline engine will Improve in the future a portion of the Improvements especially engine friction reduction may be used beneficially for diesels as well Use may be strongly limited by emission regulations and consumer reluctance

Electric hybrids involve combining an electric motor and battery with another power source in one of multiple combinations Examples Include using a constant-speed engine (Internal combustion or turbine) as a generator to recharge the battery during longer trips with electric motors driving the wheels and the battery providing all power for shorter trips and a fuel cell or engine/generator to provide power for the electric motors with a battery that allows temporary boosts for acceleration or hill climbing (to reduce the required size of the fuel cell or engine)

SOURCE Office of Technology Assessment 1994

FIGURE 2-3: Auto Fuel Costs vs. Total Costs



SOURCE Oak Ridge National Laboratory

efficiency is lack of strong market pressure for such increases. With lower gasoline prices (and lower expectations for price increases), relatively high *nonfuel* vehicle operating costs, and the average fuel economy of most new vehicles already in the 20 to 35 mpg range. fuel costs have become a smaller fraction of total costs (figure 2-3) and fuel efficiency has declined dramatically in importance as a factor in choosing a new vehicle. If cost-effective efficiency improvements are available, the overall cost savings over vehicle lifetimes of any efficiency gain will be a small fraction of the total costs of ownership and operation.[134]

Other factors likely to restrain increases in fleet fuel efficiency include the following:

- **Growth in the use of light trucks for passenger travel.** Light-truck vmt grew at a rate that was more than five times that of autos between 1970 and 1985; during this period, auto vmt grew 38 percent while light truck vmt tripled.[135] (As noted earlier, this seems to be total 2-axle, 4-tire truck travel, not personal light truck travel).
- **A growing attraction among purchasers of new automobiles to more powerful (and thus less fuel-efficient) automobiles.** An important consequence of this consumer preference has been that drivetrain improvements (such as engines with four valves per cylinder and turbochargers), with the potential to either increase fuel efficiency (at least in part by reducing engine displacement) or boost horsepower from previous levels, have been introduced in configurations that emphasize power increases rather than fuel savings. The performance increases of the 1980s, signified by a reduction in 0- to 60-mph acceleration time of 2.3 seconds from 1982 to 1990, have caused a more than 8 percent decline in fuel economy-more than 2 mpg—from what it would have been at 1982-level performance.[136]
- **Additional luxury and safety equipment on new cars.** Equipment such as power seats, sunroofs, and power locks and windows may gain additional market share and can add significant weight to the vehicle. Four-wheel drive may add 150 to 200 pounds per vehicle and decrease fuel economy by 12 to 15 percent. Safety equipment such as air bags (30 to 45 pounds) and antilock brakes (30 to 45 pounds) add further weight.
- **More stringent emission standards, especially for nitrogen oxides.** Meeting the new Tier 1 Federal standards on exhaust and evaporative hydrocarbons and nitrogen oxides may create a fuel economy penalty, although there is controversy about the likelihood of such a penalty. The California Air Resources Board claims

[134] See, for example, J. Goldemberg et al., *Energy for a Sustainable World* (Washington, DC: World Resources Institute, September 1987).

[135] Patterson, op. cit., footnote 115.

[136] K. Hellman, U.S. Environmental Protection Agency, Ann Arbor, MI, personal communication, 1990.

that the new Federal standards, and even more stringent California standards, can be met with no reduction in fuel economy.[137] In contrast, Energy and Environmental Analysis, Inc., which has extensive experience in fuel economy analysis, projects an average 1 percent fuel economy penalty from Tier 1 standards.[138]

- **Slower replacement of the automobile fleet, so that technological improvements introduced into the new fleet will take longer to diffuse into the total fleet.** Whereas in 1969 autos more than 10 years old accounted for only about 7 percent of vmt and fuel consumed, by 1977 these older vehicles accounted for about 13 percent of vmt and fuel, and by 1983 for almost 20 percent of vmt and 23 percent of fuel.[139] Continuation of this trend will slow fuel economy improvements in the fleet.
- **Changes in levels of congestion, highway speeds, and the share of urban driving, all of which impact on-road fuel economy.** Estimates of future fuel use must account for the gap between fuel economy as tested by the U.S. Environmental Protection Agency (EPA) and the actual fuel economy obtained during driving. EPA adjusts its new auto test values downward by 15 percent to account for this gap—reflecting an assumed 55 to 45 percent split between urban and highway driving, a 10 percent gap between tested and actual city fuel economy. and a 22 percent gap between tested and actual highway fuel economy.

Recent work by a U.S. Department of Energy contractor estimates the actual gap for the entire on-road fleet to be about 15.2 percent for automobiles and 24.5 percent for light trucks.[140] All else equal, increased levels of congestion, an increasing share of urban travel. and higher highway speeds would cause this gap to increase.[141] Trends in congestion and urban-rural travel clearly imply that the first two conditions will occur; and recent trends toward a higher percentage of vehicles traveling at more than 55 mph and a relatively short-term upward trend of average highway speed may indicate a future increase in this latter variable. The contractor projected a minimum gap of 21.2 percent for automobiles and 29.5 percent for light trucks by 2010, with substantial potential for a much larger gap in this time frame with slightly different assumptions.[142] These estimates should be treated with caution, however. Much of the new "urban" travel will likely occur in less congested suburbs. and ""city" fuel efficiencies may not apply. Further. EPA regulations requiring on-board diagnostics, cold temperature carbon monoxide controls, and improved evaporative emission controls will tend to reduce the tested and on-road gap.[143]

Air Passenger Travel

Passenger travel in commercial aircraft has been the United States most rapidly growing transport mode, with revenue passenger-miles increasing at the very high rate of 6.47 percent a year between

[137] James Lerner, California Air Resources Board, Sacramento, CA, personal communication, Oct. 8, 1993.

[138] K.G. Duleep, Energy and Environmental Analysis, Inc., Arlington, VA personal communication, Nov. 18, 1993.

[139] U.S. Department of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector. Progress Report One: Context and Analytical Framework*, DOE/PE-0080 (Washington, DC: January 1988).

[140] J.D. Maples, University of Tennessee Transportation Center, Knoxville, "The Light Duty Vehicle MPG Gap: Its Size Today and Potential Impacts in the Future," draft, November 1992. Another source estimates an 18.7 percent gap for automobiles and 20.1 percent gap for light trucks (M.M. Mintz et al., Argonne National Laboratory, "Differences Between EPA-Test and In-Use Fuel Economy: Are the Correction Factors Correct?" *Transportation Research Record*, No. 1416 (Washington, DC: National Academy Press, October 1993).

[141] Estimated loss in fuel economy for each mile-per-hour increase in speed between 55 and 65 mpg is 1.78 percent, according to an Oak Ridge National Laboratory study (Maples, op. cit., footnote 140).

[142] Ibid.

[143] J. German, U.S. Environmental Protection Agency, Ann Arbor, MI, personal communication, Sept. 30, 1993.

1970 and 1985.[144] At the same time, however, a combination of improved technical efficiency and advances in operations essentially doubled overall efficiency (measured in Btu per revenue passenger-mile) during the same period, so that actual energy use rose only at 1.68 percent per year. During the past few decades, commercial aviation has captured a growing share of intercity travel, primarily from automobiles, and it is likely to continue to do so even in relatively short hauls of a few hundred miles unless major new competitive systems (e.g., high-speed rail) are initiated.

In the past, the amount of air travel has appeared to be extremely sensitive to overall economic conditions and ticket prices. High economic growth rates appear to accelerate air travel; thus travel forecasts will vary depending on assumptions about GNP growth rate. If historic trends continue, any increase in growth of GNP will be accompanied by an increase in air travel that is about twice as large, in percentage terms. Similarly, an increase in ticket prices will be met by a decrease in travel demand on the order of half as large. Although ticket prices vary for many reasons, the price of jet fuel is a major influence, so travel demand will be sensitive to oil prices.

The second component of aviation energy use, fuel efficiency, will continue to increase. Most airlines are renewing their fleets (although the financial difficulties experienced recently by many airlines will slow the rate of renewal), and the new airplanes are substantially more efficient. Near-term technologies used to enhance fuel efficiency include advanced electronic controls, higher pressure ratios and turbine entry temperatures for engines, and use of composite materials that reduce airframe weight. Future technologies include continuing improvements in compressor and turbine efficiency, more extensive use of composites and other advanced materials, use of new engines such as the ultrahigh bypass turbofan and the propfan, and use of active controls for aerodynamic surfaces, to minimize drag.[145] Because fuel prices have been relatively low, there is some doubt about the likely speed of introduction of some new technologies (e.g., the propfan). Box 2-C provides a more complete description of available aircraft fuel efficiency technologies.

Aside from buying aircraft with greater technical efficiency, airlines can improve overall fuel efficiency by improving operations and continuing current trends toward larger aircraft. Relieving airport congestion is a major concern. Although some new airports will be built, expansion of airport capacity is *not* expected to be a primary strategy for relieving congestion over the next few decades.[146] Instead, most attention will go to operational modifications; for example, improvements in air traffic control systems can allow reduced spacing of takeoffs and landings and increased use of parallel runways.

An important determinant of fuel efficiency will be the distribution of aircraft trip lengths. Limitations on airport construction and forecasts of growing air traffic congestion may lead to efforts to substitute other modes-such as high-speed trains—for shorter trips. However, the recent history of commercial aviation has seen the industry capturing market share in shorter-length trips, and it is virtually unchallenged in trips of longer length (more than 500 miles). Shorter trips decrease efficiency by increasing the percentage of fuel used for taxiing, idling, and takeoff and landing, activities whose fuel use is independent of travel distance; preventing the use of larger,

144 M.M. Mintz and A.D. Vyas, *Forecast of Transportation Energy Demand Through the Year 2010*, ANL ESD-9 (Argonne, IL: Argonne National Laboratory, revised April 1991).

145 Ibid.

146 Ibid.

BOX 2-C: Fuel Economy Technologies for Commercial Aircraft

Advanced engine types. The current-generation engine penetrating the fleet today is the high-bypass *turbofan,* with heat-resistant materials that allow high turbine relet temperatures and new compressors that allow higher pressure. *Ducted ultrahigh-bypass (UHB) turbofans* yield efficiency Improvements of 10 to 20 percent *Propfan engines* deliver an additional 10 percent Improvement over UHB turbofans

Lightweight composite materials. With the exception of a few new business jets, commercial aircraft use new composite materials sparingly Extensive use of these materials can reduce airframe weight up to 30 percent without sacrificing structural strength

Advanced aerodynamics. This involves optimization of airflow using a combination of computer-designed changes in wing shapes, ultrasmooth surfaces, and "active" flow control concepts that suck air into the wings Other concepts use variable wing shapes and new fuselage designs

SOURCE D L Greene, "Energy Efficiency Improvement of Commercial Aircraft Ar?nua/Review of *Energy and the Environment* VOI **17 1992 pp 537-573**

more efficient aircraft; and generally preventing the attainment of high load factors because high trip frequency is necessary to compete successfully with other modes. ' 47

Freight Transport

The production and consumption of goods determines the demand for freight transport services, and indirectly the energy needs of the freight transport system. Although it is very difficult to forecast production and consumption, most analysts predict relatively slow growth for basic commodities. For example, coal production, which accounts for the bulk of both train and barge movements, is projected to grow at only 1.3 percent per year. On the other hand, higher-value-added goods, such as construction materials and processed foods, are expected to grow more rapidly—l.5 to 4 percent per year (table 2-5), A separate analysis predicted little or no growth for basic materials production in the United States through the year 2000.48

These projected trends—slow growth in commodities, more rapid growth in higher-value-added goods-suggest that in the future, as in the past. demand for train and barge freight movements will grow slowly, whereas demand for truck and air freight movements will grow more rapidly. However, even with extremely rapid growth of 10 percent per year for airfreight, the energy required for air freight movements will still be a fraction of that required by trucks. **Trucks will be the dominant freight transport energy consumer in the next** 20 **years.**

Commercial trucking

In 1989, trucks accounted for 29 percent of freight movements (measured in ton-miles) and used 83 percent of the energy expended for these freight shipments (table 2-2). Although the former percentage is low by European standards, the large U.S. land mass and extensive long-distance shipment of raw materials (coal, iron ore, grains) by unit trains and barges signify that truck transport actually competes very well in the interstate freight arena. Trucking dominates local distribution, of course.

The reasons for this competitiveness include the dispersed and shifting location of many products that require long-distance shipping (e. g.,

[147] A.B. Rose, *Energy Intensity and Related Parameters of Selected Transportation Modes: Passenger Movements*, ORNL-5506 (Oak Ridge, TN: Oak Ridge National Laboratory, January 1979).

[148] Williams et al., op. cit., footnote 94.

TABLE 2-5: Projected Growth in Commodities (annual average growth rate)

Commodities[a]		Goods[b]	
Coal production	13	Construction materials	3-4
Crude 011 production	-10	Appliances	2
Oil products consumption	10	Processed foods	
Agriculture production	18	Fruits and vegetables	2
Chemical production	31	Bakery items	15-2
Mining production	-01	Candy	2-35

[a] For 1990 to 2010 Coal and 011 are in Btu per year Agriculture chemicals and mining are in constant dollars U S Department of Energy, Energy Information Administration *Annual Energy Outlook 7993,* DOE /E IA-0383(93) (Washington DC January 1993), p 81, U S Department of Energy, Energy information Administration *Energy Consumption and Conservation Potential Supporting Analysis for the National Energy Strategy,* SR/NES/90-02 (Washington DC December 1990) p 126

[b] For 1993 to 1997-98 U S Department of Commerce International Trade Administration *U S Industrial Outlook 1993* (Washington DC 1993), various pages

wood), the dispersed locations to which the products (farm products) are shipped, and established truck-oriented distribution systems (petroleum products, processed foods). Trucking also benefits from an infrastructure built largely with money collected from automobile fuel taxes; although trucks pay fuel and use taxes, these taxes do not cover their proportional share of infrastructure costs.[149] Nevertheless, there is room for future shifts in freight modes, stemming from competition with more efficient rail operations that integrate with local trucking systems or from changes in the basic economics of trucking operations (higher fuel prices, higher road taxes to account for actual infrastructure maintenance costs). On the other hand, continued shifts in the U.S. economy toward service industries and higher-value-added products, with more focus on just-in-time distribution systems, may favor the flexibility of trucking over other freight transport modes and add to its share of overall freight shipment. However, at the same time these shifts in the economy may cut down the total volume of freight shipment (light engineering is less freight intensive than steel and auto manufacturing, and services are generally less freight intensive than manufacturing).

Generally, future growth in truck transport levels is expected to follow trends in economic activity, and forecasts attempt to match estimates of truck ton-miles carried to estimates of the growth of specific portions of the U.S. economy. If the U.S. economy continues its shift toward less heavy manufacturing and more services, with resulting overall freight volumes growing more slowly than the rate of GNP growth, trucking volumes may still keep pace with GNP, at the expense of other modes.

The overall energy efficiency of truck shipping depends heavily on factor-s besides simply the technical efficiency of the vehicles. These include load factors (including the incidence of empty backhauls); driver behavior; road congestion; changing speed limits, especially on rural interstate; and shifting truck mixes, including use of tandems.

Freight truck fuel efficiency, as measured in miles per gallon. has improved only gradually during the past few decades: at an annual rate of 0.4 percent per year for single-unit trucks and 0.7 percent per year for combination trucks. Furthermore, efficiency growth stagnated during the 1980s—for the period 1982-90. single-unit truck

[149] Congressional Budget Office, *Paying for Highways, Airways, and Waterways* (Washington DC: May 1992).

efficiency grew at only 0.3 percent per year, and heavy truck efficiency at 0.5 percent per year.[150] As discussed above, these aggregate efficiency indicators reflect a number of factors, including shifts in average truck size, changes in types of freight moved, and increased speed limits.

The range of factors both hindering and promoting freight truck fuel efficiency, discussed earlier, will likely continue to yield slow improvement. Commercially available technologies, such as aerodynamic improvements and electronic engine controls, will gradually increase their market penetration. Improved operations, aided by better communications between trucks and their headquarters, could increase load factors and allow more efficient routing. On the other hand, as long as fuel prices are low, trucks will likely find time savings from higher speeds out weighing the energy penalty; average highway speeds may continue to climb. Also, some projections of increases in urban congestion have been startling; if these projections are correct. future congestion could have a substantial negative impact on efficiency.[151]

It is important to note that although truck fuel efficiency is expected to improve quite slowly, a number of technological and operational improvements are available that could yield dramatic improvements in efficiency (see boxes 2-D and 2-E). The combined effects of some of these options can be estimated through the performance of trucks that use these technologies. Several manufacturers have used long-distance demonstration runs to both test and demonstrate new energy-efficient technologies. These demonstration runs combine improved technologies, highly trained drivers, and optimal running conditions (such as maintaining 55 mph). The results, summarized in table 2-6, show that commercially available trucks obtained energy efficiency 50 to 70 percent above that of the current fleet, while prototype technologies achieved efficiencies over twice that of the current fleet. These results must be applied with caution; they do not measure what could be obtained from technological improvements alone. Nevertheless. they do provide a useful upper bound for the savings potential. If all heavy trucks were able to achieve the level of energy efficiency obtained from these tests of the best commercially available technologies, energy use would drop by about 0.9 quads. or 15 percent of total freight transport energy use.[152] Achieving the energy-efficiency level of the prototype truck would be quite difficult on today roads, as it makes use of spoilers with very little ground clearance.

Alternative Forecasts

This section presents and discusses the forecasts of the Energy Information Administration (EIA) for the period 1990-2010, from its "' 1993 Annual Energy Outlook, "[153] as well as alternative forecasts from other organizations when they present significantly different projections of energy consumption or other variables affecting c(msump-(ion.

The 1993 Annual Energy Outlook (AEO93) examines seven scenarios of the future: a baseline scenario, two scenarios examining the effects of higher and lower oil prices ($38 and $18 per barrel, respectively, in 2010 versus the baseline of $29 per barrel (bbl)—all in 1991 dollars), two

150 Davis and Strang, op. cit., footnote 8, pp. 3-40, 3-42. Data are fleet average miles per gallon and exclude 2-axle, 4-tire trucks.

151 Note that moderate highway congestion, in slowing average speeds below high "free-flowing" levels, could improve fuel efficiency. However, once congestion thresholds are reached, relatively small increases in traffic can slow average speeds to 30 mph or less, or even to stop-and-go levels, which are extremely wasteful of fuel. Federal Highway Administration congestion estimates project large costs from wasted fuel.

152 Best commercially available trucks are 62 percent more efficient than existing fleet (see table 2-6, average of 51 and 72 percent); therefore replacing fleet will reduce energy use (1-[1/1.62]) or 38 percent. Heavy trucks account for about 51 percent of truck energy use (table 2-3), trucks use 4.9 quads per year (table 2-2); therefore savings = 4.9 x .38 x .51 = 0.9 quads.

153 Energy Information Administration, op. cit., footnote 10.

BOX 2-D: Fuel Economy Technologies for Commercial Trucks

Aerodynamics. Modifying the shape of the truck and trailer can yield significant reductions in energy use by reducing air resistance. The primary aerodynamic improvement used on heavy trucks today is the cab-mounted air deflector, which began to be installed in the 1970s. Since then, a number of improved aerodynamic devices have been used, including various devices to seal the space between the truck and the trailer, front air dams, and improved rooftop fairings. The simpler devices can often be retrofit to existing trucks and, according to one analysis, offer rapid (less than 2-year) paybacks.[1] Aerodynamic improvements to trailers include side skirts to minimize turbulence underneath the trailer and rear "boattails" to smooth airflow behind the trailer The energy savings of these devices are difficult to measure, since airflow is difficult to model accurately and field tests are complicated by the need to measure small effects while controlling for confounding factors such as wind speed, temperature, and driver behavior, Aerodynamic Improvements to tractor-trailers are also limited by the need to connect quickly and simply to trailers of different designs and sizes, to tolerate road surface uncertainties, and to meet size regulations,

Improved tires. Radial tires have largely replaced bias-ply tires, except for special applications such as off-road use (bias-ply tires have stronger sidewalls and are thus more resistant to puncture). By one estimate, replacing all 18 bias-ply tires on a full-size tractor-trailer with radials results in a 10 percent reduction in fuel use in miles per gallon[2] A more recent tire innovation is "low-profile" radial tires, which weigh less than standard radials and thereby save energy, Just now becoming commercially available are "low rolling resistance" tires, which use new compounds and designs to reduce rolling resistance. These new tires are claimed to offer a potential energy savings of 4 percent relative to low-profile tires[3] and 75 percent relative to conventional radials[4] Finally, fuel savings can be achieved by tailoring tires to specific types of service, powertrains, and roads, including the use of smaller-diameter tires for low-density cargo

(continued)

[1] H Sachs et al , *Heavy Truck Fuel Economy* (Washington, DC American Council for an Energy -Efficient Economy, January 1992), p 16

[2] Bridgestone Tire Co., *Guide to Large Truck Fuel Economy for the 90's* (Nashville, TN 1992), p 7

[3] "Tomorrow's Tire Today, " *Fleet Owner,* September 1991, P 48

[4] Kenneth Farber, representing Michelin Personal Transportation Vehicle Workshop, presentation to White House Conference on Global Climate Change, Washington, DC, July 1,1993 Current market share of low rolling resistance radials was said to be5percent

scenarios examining the effects of higher or lower economic growth rates (2.4 and 1.6 percent per year, respectively, versus the baseline of 2.0 percent per year), and two scenarios examining the effects of high or low domestic gas and oil recovery (40.2 versus 31.9 quads recovered, respectively, compared with 33.8 quads in the baseline scenario).[154] None of the scenarios is policy-driven in the sense that all assume that little change will occur in government policy to affect energy supply and demand. That is, the scenarios assume no major new conservation initiatives, such as more stringent fuel economy standards or tax incentives for purchase of fuel-efficient autos, and no important changes in access to energy supplies. (A modest exception is assumed passage of licensing reform legislation for new nuclear reactors in the high-economic-growth case.)

[154] High and low recovery rates are based on the probability distribution of technically recoverable oil and gas reserves in the United States as estimated by the U.S. Geological Survey. The baseline case is the median of the distribution, whereas the high and low cases are based on the 5th and 95th percentiles, respectively.

BOX 2-D: Fuel Economy Technologies for Commercial Trucks (cont'd.)

and of very wide single tires to replace dual tires. However truck tires, unlike automobile tires are often re-capped when worn low-profile and low rolling resistance technologies which cannot be Incorporated into recapped tires will largely be limited to sales of new tires

Improved transmissions. Electronic transmission controls measure vehicle and engine speed and other operating conditions allowing the transmission to optimize gear selection and timing thus keeping the engine closer to optimal conditions for either fuel economy or power than is possible with hydraulic controls This technology offers about a 4 percent improvement in fuel economy.

Greater use of diesel engines. Compression-ignition engines, or diesels, are a proven technology and are significantly more efficient (about 12 percent for heavy trucks) than gasoline two-valve engines even at constant performance, new direct injection turbocharged diesels offer additional fuel savings.

Improved engines. A variety of new engines are becoming available to freight trucks. *Turbocompound engines* are technically ready but have not been commercialized because of low fuel prices. *Low-heat-rejection diesels* are compression-ignition engines that run at very high temperature and do not use energy-draining cooling systems. *Gas turbines* harness fuel energy by using the burning fuel's kinetic energy to spin a turbine rather than drive a piston. Both engine types require the development of mass-producible materials with higher heat resistance than currently available (structural ceramics or heat-insulating composites). Estimated fuel savings for low-heat-rejection diesels are as high as one-third over modern diesels.[5]

Electronic engine controls. Electronic engine control systems can monitor and adjust fuel consumption, engine speed, idle time, road speed, and other factors. They can also provide extensive feedback data to drivers on energy use. They were developed largely to meet new emissions requirements, but they have energy-efficiency benefits as well. They are currently available on some long-haul heavy trucks.

SOURCE M M Mintz and A D Vyas Forecast of Transportation Energy Demand Through the Year 2010 Argonne National Laboratory Report ANL F SD-9 revised April 1991

[5] R Kamo Adiabatic Diesel-Englrw Technology in Future Transportation *Energy* vol 12 No 10 11 1987 pp 1073 1080 cited in D L Greene et al Transportation Energy to the Year 2020 *A Look Ahead Year 2020* Transportation Research Board Special Report 220 (Washington DC National Academy Press 1 988)

The baseline scenario accepts mainstream ideas about oil prices and economic growth. First, the scenario assumes that a combination of plentiful oil supply, gradually increasing world demand, and Saudi restraint will maintain prices in the $20/bbl range for a few years and then gradually push prices upward, to $29/bbl (1991 dollar-s) by 2010, with a gradual increase in gasoline retail costs. Second, it assumes that slower growth in the U.S. labor force for the next few decades (a projected rate of about 1 percent per year versus 2.1 percent annually from 1970 to 1 990) will restrain the growth in real output of goods and services, but that the U.S. economy will remain sufficiently competitive in world markets to keep growing at the moderate rate of 2.0 percent per year. The alternative price scenarios reflect. on the low side, a combination of aggressive conservation, significant competition among Organization of Petroleum Exporting Countries

BOX 2-E: Operational Strategies To Improve Truck Fuel Efficiency

Speed. Several studies have examined the effects of higher speed on energy consumption One field test found a fuel efficiency penalty of 22 percent from increasing speeds from 55 to 65 mph.[1] Other costs associated with increased speed were reported as well, including a 10 percent decrease in miles to engine overhaul These costs, however, must be traded off against time savings For a 1,000-mile trip, traveling 55 instead of 65 mph in a new tractor-trailer will save 278 gallons of fuel but will take an extra 28 hours At $1 25 per gallon the fuel savings are equivalent to a time cost of $12.40 per hour If driver salaries or the time value of the cargo exceed this, then it may be financially prudent to drive 65 mph [2]

Idling. Truck drivers often idle their engines for long periods—to supply heat or air conditioning for the cab, to keep fuel heated and free-flowing, to avoid starting difficulties, and because starting is thought to be hard on the engine Fuel consumption at idle varies, but a typical rate is O 5 gallons per hour.[3] In addition there are other detrimental side effects of idling, including oil degradation and Increased engine wear due to water condensation.[4] The technical alternatives to idling include using auxiliary cab heaters and air conditioners, fueled by diesel or electricity, and fuel and engine block heaters, which are also available at low cost [5] Concerns over starting are certainly valid, however, if batteries are in good condition a truck should have no difficulty starting Claims that starting is hard on the engine are unproven and have no apparent engineering basis Unfortunately there are no reliable estimates of total fuel consumed by excess Idling, so savings potential is unknown

Routing and operations. Advanced communication and computer technologies have already improved truck operations, and further Improvements are likely Some truck fleet operators are using commercially available software packages to determine optimal loading and routing.[6] A few large fleets are using onboard computers and/or satellite communications to track fleets and provide up-to-date information to drivers.[7] As the costs of such systems decline and customers increasingly require up-to-date information

(continued)

1 American Trucking Associations, The Maintenance Council 55 vs 65 *An Equipment Operating Costs Comparison* (Alexandra VA 1987), p 7

2 Assuming 6 44 mpg at 55 mph and 546 mpg at 65 mph as found by ibid Extending the analysis to include effects on engine life has little effect on the results Many drivers are paid by the mile and not by the hour, in these cases the time penalty for slower speeds is paid by the driver (who must work longer hours for the same pay) and not by the owner

3 "Electronic Diesels and Other Ways to Improve Fuel Economy, *Commercial Carrier Journal,* April 1993, p 96

4 Argonne National Laboratory, "Don t Idle Your Profits Away! October 1986. P 3

5 Ibid

6 Abacus Technology Corp, "Rail vs Truck Fuel Efficiency,' report for the Federal Railroad Administration April 1991 p 2-12

7 R Schneidermann, "Tracking Trucks by Satellite" *High Technology Business*, May 1989 p 24

(OPEC) members to expand production capacity, and high non-OPEC production, perhaps because of a revival of production capacity in the former Soviet Union.[155] On the high side, the alternative price scenarios reflect more global economic growth and less conservation than expected (boosting world oil demand), coupled with lower supply. The alternative-economic-growth scenarios reflect differing assumptions about the rate of labor force growth and productivity: 1.2 percent annual growth in the labor force and 1.2 percent annual productivity growth (versus a baseline of 1 percent productivity growth) for the high economic growth scenario, and 0.8 percent labor force

155 Given the Continuing political turmoil in the Confederation of Independent States (CIS), the DRI forecast expects CIS production to be significantly delayed by negotiations and startup problems.

BOX 2-E: Operational Strategies To Improve Truck Fuel Efficiency (cont'd.)

on the status and location of their goods, these systems will become more prevalent The energy savings will come from Improved routing reduced empty or partially filled truckloads due to better Information on availability of loads and trucks, and more efficient operations at transfer points

Reduced empty backhauls. Although the data are uncertain, about 10 percent of long-distance truck-miles are empty[8] Reasons for empty backhauls Include equipment limitations (e g , an automobile carrier cannot carry other cargo) and natural traffic Imbalances (e g , urban areas consume more than they produce) Regulatory restrictions once prohibited private companies from carrying cargo for others, however, many of these restrictions were removed by the Motor Carrier Act of 1980 It may be possible for Improved communication and information tools to allow for better matching of loads and trucks, thereby further reducing empty backhauls

Increased size and weight. Allowable truck size and weight are controlled by both State and Federal law The Surface Transportation Assistance Act (1 982) prohibits States from setting a maximum gross weight of less than 80,000 pounds for travel on or near interstate highways. In addition, States are required to allow trailers 48 feet long, or double trailers 28 feet long and 102 inches wide The Intermodal Surface Transportation Efficiency Act of 1991 prohibits States that do not already do so from allowing longer trucks on or near Interstate highways Currently some but not all States allow longer trucks, however, the variations in State rules make it difficult for longer trucks to operate on Interstate long-haul routes

SOURCE Off Ice of Technology Assessment 1994

[8] Estimate by OTA staff based on various sources

growth and 0.8 percent productivity growth for the low-economic-growth case. The gas and oil supply scenarios have little effect on the rate of economic growth or energy use from 1990to2010 compared with the base case.[156]

Other forecasts predict moderate growth in the economy and world oil prices similar to the AEO93 baseline scenario. The annual rate of change in GDP for the Gas Research Institute Baseline Projection 1993 (GRI93)[157] is identical to the AEO93 (2 percent) whereas the DRI/McGraw Hill Spring/Summer Energy Forecast (DRI)[158] assumes a 2.2 percent GDP growth rate. The Argonne National Laboratory's Transportation Energy and Emissions Modeling System (TEEMS)[159] uses the DRI macroeconomic submodel for its forecast, so assumptions are similar.[160]

AEO93 projects moderate but steady growth in transportation energy use across all scenarios: baseline growth is 1.26 percent a year, with a range of 0.9 to 1.6 percent annually for the other

156 However [here, $ a 10 percent increase in imported petroleum (1.26 million barrels a day, mmbd) in the low oil and gas recovery scenario and an I I percent decrease in imported petroleum (1.35 mmbd) in the high oil and gas recovery scenario. Total consumption of energy differs by 0.5 quadrillion Btu (quads) between the high and low recovery scenarios and the reference case, or less than 0.5 percent of total consumption.

157 P. D Holtberg et al. *Baseline Projection Data Book: GRI Baseline Projection of U.S. Energy Supply and Demand 102010,* vol. 1 (Washington, DC. Gas Research Institute, 1993).

158 DRI McGraw -Hill, *Energy Review* (Lexington, MA: spring/summer 1993).

159 Mintz and Vyas, op. cit., footnote 144.

160 Ibid., pp. 8-9.

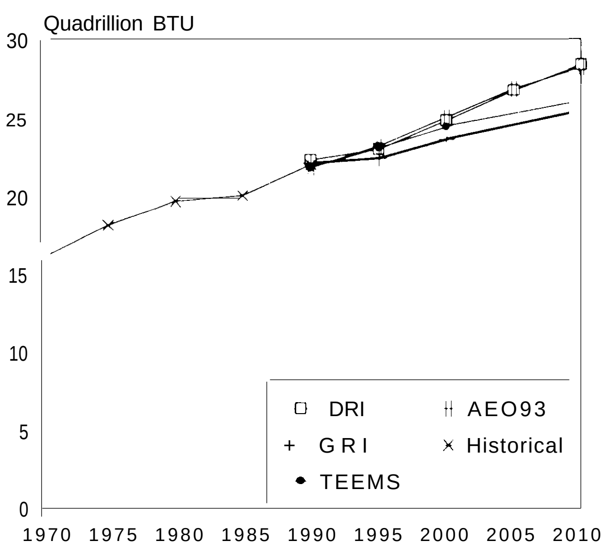
TABLE 2-6: High-Efficiency Heavy Trucks

Truck	Gross weight (lbs.)	Fuel economy Mpg	Fuel economy Percent over existing fleet
Existing fleet	33,000 and over	5 3	—
Kenworth T600A	72,400	8 0	51
Peterbilt 377A/E	76700	91	72
Kenworth prototype	72050	114	115

SOURCES Existing fleet average from S C Davis and M D Morris, *Transportation Energy Data Book,* ed 12, ORNL-671 O (Oak Ridge TN Oak Ridge National Laboratory, March 1992), p 3-46 Truck efficiencies based on cross-counrty demonstration runs using trained drivers See J McNamara, "Kenworth Road Test Raises Fuel Economy Target," *Transport Topics,* Dec 10, 1990, **p 12, and** T Moore, "Peterbilt Introduces Aero Con-ventional," *Fleet O-wrier* November 1991 p 10

scenarios. Over the 20-year forecast period, this means that transportation energy use will grow from the 1990 level of 22.50 quads. slightly more than 10.5 million barrels per day (mmbd), to 26,86 to 31 quads, about 12.9 to 14.9 mmbd (a 19.0 to 37.8 percent increase) by 2010. The baseline2010 figures are 28.93 quads (13.9 mmbd) total, a 28.5 percent increase (see figure 2-4[161]).

FIGURE 2-4: Total Energy Use of the U.S. Transportation Sector



SOURCE Off Ice of Technology Assessment based on Energy Information Administration historical data and various forecasts

DRI forecasts growth in energy use almost identical to the AEO93 baseline case (i.e., 1.2 percent per year to 28.22 quads, or 13.3 mmbd, in 20 10-or an increase of 27 percent). However, its components (types of fuels, vehicle-miles traveled, and fuel efficiency) are at different levels of growth. DRI forecasts a higher annual total energy growth rate in the second 10 years than AEO93 (1.30 versus 1.09 percent) despite a decrease in the growth rate of highway motor fuel use. AEO93 forecasts a higher energy growth rate than DRI in the first 10 years (1.35 versus 1.18 percent) with a similar decline in highway fuel use. GDP and total vmt projections are similar in the two forecasts. with much of the difference coming from AEO93's more optimistic forecasts of fuel efficiencies.

GRI forecasts a low growth rate in energy use at 0.68 percent a year. The total transportation sector energy use in 2010 is 25.46 quads (11.86 mmbd), a 14.5 percent increase from 1990 and 12 percent less than the AEO93 forecast. Much of this difference comes from a projected **decrease** in motor gasoline consumption over the next 20 years despite a robust growth in motor vehicle vmt. Assumed fuel efficiency ratings are higher not only for passenger cars, but also for light-duty trucks, whose use all models project will continue to grow at a faster rate than passenger car use, with lower fuel efficiency gains.

[161] All charts referencing AEO93 projections will use the baseline scenario.

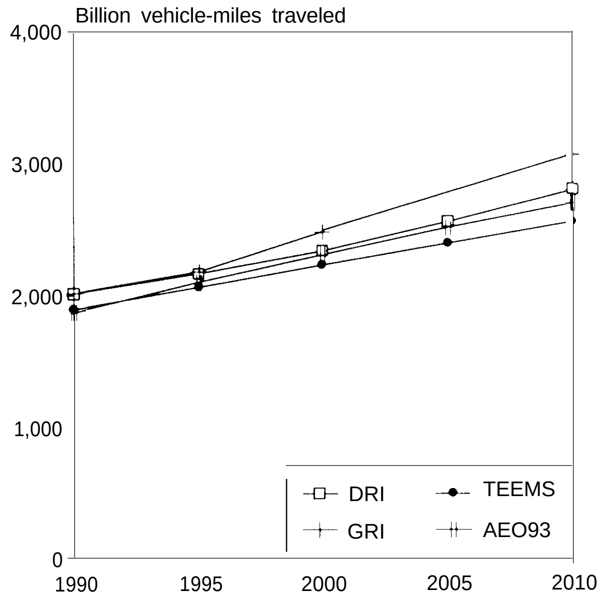
TEEMS forecasts a total energy annual growth rate of less than 1 percent, with a sharp decrease in the second decade of the projection (1.15 to 0.67 percent). Total transportation energy use increases from 21.86 to 26.19 quads (1 2.2 mmbd), an increase of slightly less than 20 percent from 1990 and 9.5 percent lower than AEO93's 2010 total. Part of this 9.5 percent difference can be explained by EIA's higher 1990 estimate of energy consumed by heavy-duty trucks. Another important reason is a lower expected growth rate in air transportation for the TEEMS model (1 .05 percent) than for the AEO93 model (1.9 percent).

In the AEO93 forecast, motor gasoline remains the dominant fuel, but its use increases far more slowly than diesel fuel, predominantly for freight trucks, and jet fuel for aircraft. In 1990, motor gasoline, diesel fuel, and jet fuel made up 91 percent of transportation energy. The projected baseline growth for transport use of these fuels from 1990 to 2010 is 0.8, 1.7, and 1.9 percent per year, respectively, so that diesel share grows from 17 to 18.7 percent, a gain of 1.59 quad (0.74 mmbd). Jet fuel grows from 14 to 15.8 percent, a gain of 1.44 quad (0.67 mmbd), whereas gasoline's share **decreases** from 60.3 to 55 percent, although it gains 2.33 quads (1.08 mmbd). These differences in growth occur primarily because AEO93 foresees a decrease in the annual rate of vmt growth for light-duty highway vehicles, a modest but steady increase in fuel efficiency for these vehicles, a sharp increase in the annual growth rate for air passenger travel and freight shipments, and brisk growth in truck freight transport.

Vehicle-Miles Traveled and Fuel Efficiency

Due to light-duty vehicles' large share of energy use in the transportation sector, forecasting vmt is an important component in forecasting the total sectoral energy use in 2010. In 1990, light-duty vehicles made up about 34 percent of total U.S. petroleum consumption and 14 percent of the entire energy consumed by the United States.[162]

FIGURE 2-5: Light-Duty Vehicle-Miles Traveled for Passenger Autos and Light Trucks



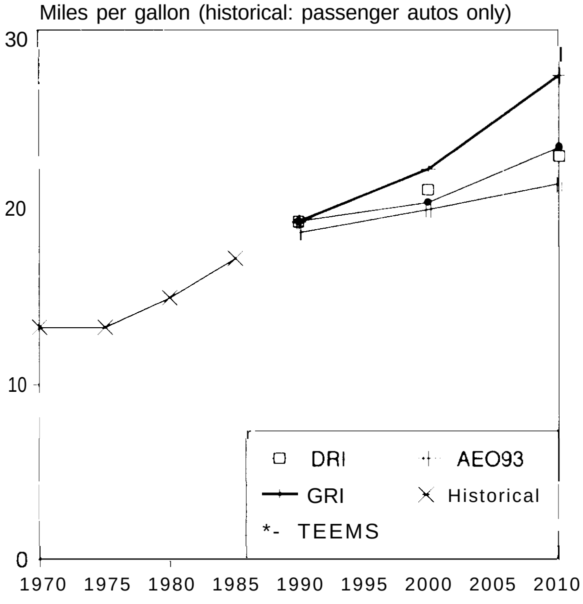
SOURCE Office of Technology Assessment, based on American Automobile Manufacturers' Association data and various forecasts

In the AEO93 baseline scenario, travel for light-duty highway vehicles grows at a much slower pace than in the past, about 1.7 percent per year (see figure 2-5), whereas the fuel efficiency of the light-duty fleet[163] grows at about 0.7 percent annually, compensating for less than half of the growth in travel demand (see figure 2-6). This yields a 1 percent annual growth in energy consumption over the next 20 years compared with 1.36 percent over the last 20 years. These parameters do not change much in the other scenarios: for

162 Motor Vehicle Manufacturers Association, *Facts and Figures '92* (Detroit, MI:1992), p. 82.

163 This value is an estimated average on-the-road efficiency rating for all cars and light trucks. The EPA rating for projected mpg for new cars is adjusted according to assumptions (coefficients) in each model for projected changes in fuel prices (e.g., AEO93 estimates that a 10 percent Increase in fuel prices yields a 6 percent improvement in fuel efficiency over time due to manufacturer product changes and consumer response) and inefficiencies such as increased congestion.

FIGURE 2-6: On-the-Road Fuel Efficiency of the Light-Duty Vehicle Fleet



SOURCE Off Ice of Technology Assessment based on Oak Ridge National Laboratory historical data and various forecasts

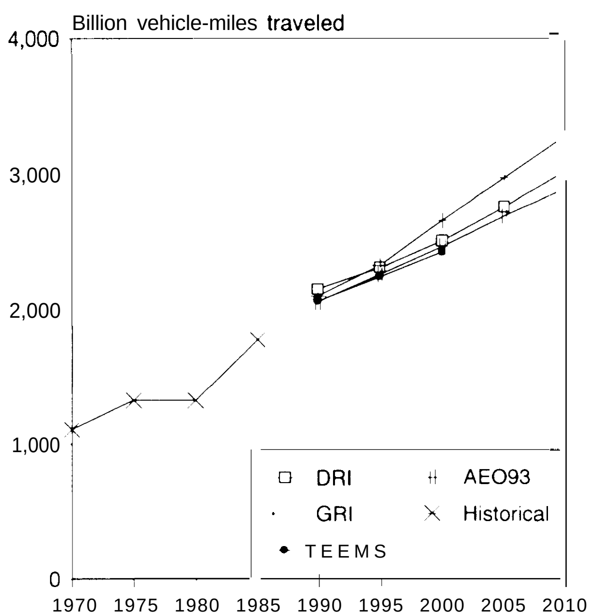
example, in the high economic growth scenario, light-duty travel grows at a pace of only 1.9 percent per year, still well below historic levels. The largest variation in fuel use occurs with low oil prices, with a 1.8 percent annual growth in travel and only a 0.5 percent annual compensating increase in fleet fuel efficiency; in this scenario, transportation use of gasoline grows at 1.3 percent a year, leading to an increase of 1.82 mmbd by 2010, a 50 percent gain from the baseline case.

Several of the alternative forecasts looked at both total and personal vehicle vmt (see figure 2-7). The forecasts rely on economic choice calculations based on fuel efficiency, real costs per mile, and real disposable income. Predictive variables come from either fleet-based or driver-based characteristics.

DRI

The DRI forecast uses a fleet-based model to calculate vmt. The mode] uses projected vehicle purchases and scrappage-rate assumptions, based on projected real costs per mile and real disposable income, to obtain a vehicle mix for the light-duty fleet in nine census-defined regions of the United States. The DRI total highway vmt forecast is almost identical to AEO93. The average annual vmt growth rate is 1.7 percent, but the total is higher due to a difference in definition of light-duty vehicles. The AEO93 model forecasts a decrease in the annual light-duty vmt growth rate in the second decade of the forecast, presumably due to a drop in the U.S. economy's growth rate (an important predictor of vmt growth in all of the models) and increased oil prices. The DRI model forecasts an increased vmt growth (1.84 percent) in the years 2000-10 despite a forecasted decrease in economic growth. Projected fuel efficiency increases by 0.9 percent a year with a slight decrease in the second decade. This results in a slightly lower motor fuel consumption in 2010 than projected in the AEO93 forecast.

FIGURE 2-7: Total Highway Vehicle-Miles Traveled



SOURCE Off Ice of Technology Assessment based on American Automobile Manufacturers Association historical data and various forecasts

Gas Research Institute

The GRI forecast uses the DRI base vmt model and adjusts some of the coefficients to reflect differing assumptions (mostly in the area of fuel efficiency and natural gas-fueled vehicle share). GRI forecasts higher fuel efficiency and one of the highest increases in total highway vmt of any of the models. The total highway vmt is expected to grow an average of 2.28 percent per year over the next 20 years to 3,288 billion vmt. Total fleet mix is expected to be 30 percent light-duty trucks, accounting for 35 percent of the total vmt in 2010. The vmt for light-duty vehicles is expected to grow at a slightly lower rate of 2.12 percent annually. Most of the excess increase in vmt (compared with other models) is offset by the higher projected increase in light duty vehicle fuel efficiency. which is expected to grow by 1.79 percent annually, from 19.2 to 27.4 mpg, or slightly less than a 43 percent increase. Given the physical limits of efficiency improvements for present-day automobile engine configurations and even conservative estimates of increased congestion, most of this increase must come from changes in consumer preference. With the moderate consumer reaction to fuel price increases in the last 20 years, the trend toward a higher percentage of older vehicles in the fleet mix, and projected moderate fuel prices,[164] it would appear difficult for the vehicle fleet to achieve this great an increase in fuel efficiency over such a short time frame. GRI projects transportation use of natural gas to increase at 3.6 percent a year, from 0.7 to 1.4 quads.[165] This represents a slightly more than 28 percent increase in natural gas vehicle use to almost 0.5 quad between 1990 and 2010. The AEO93 projects an increase in vehicle gas use from negligible to 0.15 quad during the same period.

Transportation Energy and Emissions Modeling System

TEEMS combines fleet-based and driver-based models. It uses changes in disaggregate household vmt data (driver-base) to project fleet mix by vehicle usage and scrappage rates (fleetbase) similar to the DRI model. Economic and fuel price variables are based on the DRI macromodel of the U.S. economy. TEEMS projects the lowest annual growth in total highway vmt of the forecasts examined, 1.55 percent. The model forecasts a lower annual growth rate in the second 10 years than in the first 10, in conjunction with a decrease in the annual growth rate of GDP from 2.6 to 1.93 percent. The 20- year annual growth rate of light-duty vmt is also the lowest of models at 1.49 percent, or 20 percent less than the AEO93 model growth rate. The model predicts that most of the fuel efficiency (and emissions) gains of highway vehicles will be offset by increased congestion and the large number of older, less efficient vehicles that remain on the road. Fuel efficiency increases at an annual rate of only 0.56 percent in the first decade and 1.43 percent in the second[166] for a 20-year annual rate of slightly less than 1 percent, from 19.2 to 23.4 mpg.

Air Travel

AEO93 projects that travel for air passengers and freight combined will grow much faster than any other mode, and much faster than the growth rate of the economy—at 3.9 percent per year for the baseline, and as much as 4.8 percent annually for

[164] Fuel and oil costs were slightly more than 13 percent of the total per-mile costs to operate a car. This percentage is expected to continue to decline, making fuel prices less predictive of light-duty vehicle fuel efficiency. See Davis and Strang, op. cit., footnote 8, p. 2-40.

[165] This includes pipeline compressor use of natural gas for throughput of natural gas in the lower 48 States. The amount is 0.7 quad in 1990 and increases to 0.9 quad in 2010.

[166] Presumably due to rising fuel costs.

the high-economic-growth case. Aircraft efficiency will also increase at a brisk pace—1.5 percent per year (in terms of Btu per passenger) in all of the scenarios—but not nearly fast enough to offset the growth in travel demand.

Transportation Energy and Emissions Modeling System

The TEEMS model projects a similar annual rate of increase in revenue passenger miles—3.37 percent, but greater aircraft efficiencies than the AEO93 projection, for an overall increase in jet fuel demand of 1.05 percent per year or about a 23 percent increase over the 20 years.

DRI

DRI projects the highest annual rate of increase in revenue passenger-miles for commercial jets[167] (3.82 percent per year) and lower efficiency gains (1. 15 percent per year), for an overall increase in jet fuel demand of 1.42 percent a year or about a 32.5 percent increase over the 20-year period.[168]

Rapid fuel efficiency gains are likely through lighter composite materials, advanced electronic controls to optimize fuel burn under given flight conditions, and an increase in the number of seats per aircraft.[169] However, even at a rapid rate of growth, air transport will make up a relatively small portion of the transportation sector's energy use.

Discussion and Analysis

There is a remarkable unanimity among the various models that highway vmt will increase at a much lower rate during the period 1990-2010 than during the previous decades; all models use vmt rates of less than 2 percent per year. As noted, the most important factor behind these projections is the forecasted decline in growth of driving-age adults as the baby boom passes. This factor alone represents more than half of the decline in growth rate in the EIA forecast and presumably is equally critical in the alternative forecasts. There is less unanimity about efficiency increases, although the majority of the forecasts are relatively optimistic about fuel economy, with the GRI forecast being remarkably optimistic. Similarly, all forecasts project growth in air travel at levels considerably lower than the recent 6 to 7 percent annual rate, with EIA projecting 4.8 percent for the high-economic-growth scenario, and less than 4 percent for the baseline scenario. *All of these factors tend to push passenger transportation energy consumption growth in the same direction, to lower-than-historic levels.*

OTA considers the EIA projection of transportation energy growth—a baseline increase of about 29 percent over 1990 levels by 2010-as likely to be an underestimate, if there are no changes in energy policy. In particular, OTA is skeptical that vmt growth will fall below 2 percent a year for the period and that light-duty fleet fuel economy will increase as much as EIA projects.

Freight

There have been several efforts to forecast freight transport energy use. The results of three models are presented, one of which is a very simple extrapolation of past trends used to pinpoint key areas of disagreement.

Argonne National Laboratory provides forecasts of energy use through 2010 for both freight and passenger transport. Results of the Argonne model show freight transport energy use growing by 2.3 quads from 1990 to 2010-with 1.8 of these due to increased consumption by trucks and 0.4 due to trains (table 2-7). This model projects very rapid (3.3 percent) annual growth in train

167 Includes freight and passenger demand.

168 DRI also starts off with a higher baseline level of jet fuel demand (0.6 quad) than TEEMS.

169 However, there are physical limitations to aircraft size due to current airport configurations. The lack of completely new airports completed or in the final permitting process in the past 10 years (Stapleton being the exception) will limit the size of aircraft over the next 20 years.

ton-miles, more than double the historic (1970-90) growth rate.[170] The model also projects moderate (1 percent) annual average improvements in freight truck intensity--even though historical improvements, as discussed above, were considerably smaller.

The AEO93 forecast shows a 2.4-quad increase in freight transport energy use (1990-20 10), with 1.5 of this from trucks and 0.6 from marine (table 2-8). (The EIA model, unlike the Argonne model, includes international movements under "Marine.") The increased demand for freight truck movement is relatively modest in this mode]- 1.9 percent per year, compared with 2.5 percent for the Argonne model. Other researchers have noted that EIA's growth rate for freight truck travel is surprisingly low, whereas truck efficiency improvement is rapid.[171] The EIA analysis also implies that oil prices have little or no effect on freight transport energy use. The projected improvement in freight truck energy intensity, for example, is the same at a 2010 oil price of $18 per barrel as at $38 per barrel (1991 dollars).[172]

TABLE 2-7: Argonne Forecast of Freight Transport Energy Use (quads/year)

Mode	1990	2010	Change (percent per year)
Truck	525	707	15
Train	053	095	30
Marine	034	038	06
Air freight	005	006	16
Pipeline	068	070	03
Total	**6.84**	**9.15**	**1.5**

SOURCE Argonne National Laboratory, *Forecast of Transportation Energy Demand Throughout the Year 2010* ANL ESD-9 (Argonne IL November 1990 revised April 1991) p 3

TABLE 2-8: AEO Forecast of Freight Transport Energy Use (quads/year)

Mode	1990	2010	Change (percent per year)
Freight	506	657	13
Rail	049	059	09
Marine	139	202	19
Pipelines	068	081	09
Total	**7.62**	**9.99**	**1.0**

SOURCE U S Department of Energy Energy Information Administration *Annual Energy Outlook 1993* DOE EIA-0383(93) (Washington DC January 1993) p 96

The assumptions and results of the Argonne and EIA models can be examined by comparing them with the results of a simple extrapolation of past trends. As discussed above, it seems likely that past trends (notably increasing demand for higher-value-added goods, moderate growth in basic commodity" movements, and continued moderate penetration of energy-efficient technologies) will continue. Therefore a simple extrapolation of past trends is a useful reference case.

The results of such an extrapolation are shown in table 2-9. This calculation uses historical trends in demand (ton-miles per year) and energy intensity (Btu per ton-mile) to forecast energy use. For example, to calculate train energy use in 2010. demand for train movements and train energy intensity in 2010 are calculated first by assuming that historical (1970-90) rates of change continue in the future (1990-2010). Demand and intensity in 2010 are then multiplied to yield energy use.

This simple extrapolation. in comparison with the Argonne and EIA models, shows much higher growth in freight truck energy use—3.4 percent annually versus 1.5 and 1.3 percent annually, This

[170] This increase is due to rapid expected growth in coal movements from western mines to eastern and southern powerplants

[171] D. Gately, "The U.S. Demand for Highway Travel and Motor Fuel," *The Energy Journal*, vol. 11, No. 3, 1990, pp. 59-73.

[172] Energy Information Administration, op. cit., footnote 10, pp. 6, 150, 168.

TABLE 2-9: Simple Extrapolation of Freight Transport Energy Use

	Energy use	(Quads/yr)	Growth	
Mode	1989	2010	Percent per year	Quads (1989-2010)
Truck	4.9	9 8	+3 4	4 9
Rail	0.4	0 3	-1 2	-01
Water	0 3	0 4	+1 4	01
Air	01	0 2	+4 5	01
Pipeline	0 3	0 4	+2 1	01
Total	**5.9**	**11.1**	+3.0	5.1

SOURCE. Off Ice of Technology Assessment, 1994

is due in part to the extrapolation of past trends in truck freight energy intensity, which was relatively flat from 1970 to 1990.[173] In the absence of major technological or policy changes, there is little reason to expect past trends to change.

Given the uncertainty both in the historical data and in future economic conditions and oil prices, these forecasts should be interpreted with care. One can, however, be reasonably confident about major trends shown by all three efforts-that truck energy use will continue to be much higher than that of the other modes, and that air freight will continue to be a trivial energy consumer despite the rapid growth in demand for air freight movements that is forecasted.[174]

173 As discussed above, truck energy *efficiency* (miles per gallon) improved very slowly In the past 20 years. Data on *intensity* (Btu per ton-mile) are uncertain, but show a similar pattern. In addition to the factors discussed above—such as increased highway speeds—intensity was probably influenced by decreases in cargo density, which led to trucks filling up their cargo areas before reaching (heir weight l imits. This would increase intensity, as measured by Btu per ton-mile, but is not a decrease in efficiency.

174 A fourth analysis, not discussed here, also found that truck energy will continue to dominate freight transport energy use and that air freight will continue to bea small energy user. See Union of Concerned Scientists, *America's Energy Choices* (Cambridge, MA: 1992), technical appendix, p. D- 10.