

Long-Term Outlook for Transportation Energy Demand

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ABSTRACT

A forecast of U.S. transportation energy demand by mode and fuel type is presented, and the forecast methodology, principal assumptions, and key findings are discussed. Results show steady growth in 1980 to 2010 travel demand (ranging from 28 percent for domestic waterborne commerce to 61 percent for personal vehicles, 74 percent for commercial trucks, and 157 percent for rail freight). As a result of relatively modest technological improvements and modal shifts, total transportation energy demand declines through 1990 and then rises at an increasing rate. Automobiles per household, vehicle miles of travel per household, and energy consumption per capita decline through the year 2000. Transportation energy per dollar of gross national product, freight energy per ton-mile, and passenger energy per capita continue to fall (but at a declining rate) through 2010. The forecast is compared with other long-range transportation energy forecasts that recently appeared in the literature, and certain underlying factors that influenced the forecast results are discussed. The paper concludes with several observations on the appropriate role of and focus for forecasts in general and transportation energy forecasts in particular.

The transportation sector now accounts for about 60 percent of U.S. petroleum consumption (1). This share has grown over the past decade as other sectors have shifted from petroleum to coal, electricity, or natural gas, and it is expected to continue to grow as industries and electric utilities opt for fuel flexibility in their new equipment. Transportation is the most petroleum-dependent sector; therefore, at least for the foreseeable future, analyses of petroleum demand and dependence on declining and at times unreliable fossil fuel sources must focus on the future activity and energy efficiency of transportation.

This paper presents the results of ongoing work by staff of the Center for Transportation Research at Argonne National Laboratory (ANL) in forecasting transportation energy demand by mode and fuel type to the year 2000 and beyond. Sponsored by the U.S. Department of Energy (DOE), Office of Transportation Systems (OTS), this effort is designed to provide the planning details required to guide long-range research and development program review and development. Two prior ANL forecasts, also sponsored by OTS, were published in 1979 and 1982 (2,3).

The remainder of this paper is organized into three sections: (a) an overview of the latest ANL forecast, including a brief description of methodology and key assumptions; (b) a comparison of selected features of the ANL-83N forecast and other recently published efforts; and (c) a series of observations and conclusions on both forecasting in general and the behavioral assumptions embedded in the forecasts.

THE ANL-83N FORECAST

Methodology and Key Assumptions

The ANL forecast, known as ANL-83N, was based on the latest (1983) National Energy Policy Plan (NEPP) (4). The purpose of this forecast was to provide a finer level of detail on future activity levels and energy consumption within the transportation sector consistent with the overall economics, demographics, and price assumptions of NEPP. Table 1 presents the

economic and demographic assumptions and fuel prices used in the ANL-83N forecast. The spring 1983 run (TRENDLONG2008A) of the Data Resources, Inc. (DRI), long-range macromodel was used to supplement those inputs not specifically addressed in the 1983 NEPP forecast (according to J. Stanley-Miller of the Office of Policy, Planning and Analysis, DOE) (5).

The ANL-83N forecast relies on a series of models collectively known as the Transportation Energy and Emissions Modeling System (TEEMS) (3,9). Various components of the TEEMS package have been used for forecasting personal vehicle fleet mix and purchase patterns (8), projecting freight volumes and mode splits during a petroleum shortfall (9), estimating urban demographic shifts by household type and composition (10), and investigating the relationship between commercial air carrier financial yield and air passenger miles of travel (11).

Model Structure

On the passenger side, the TEEMS package starts with a base-year distribution of households according to a five-variable identifier and a base file of household vehicle and travel characteristics for each of the associated descriptor cells, as revealed in the 1977 Nationwide Personal Transportation Study (12).

A demographic forecast is generated for each of the five variables and is deployed in an iterative proportional fitting technique to generate future household counts by cell. These in turn are input to a vehicle choice model (with personal vehicles as characterized for the given forecast year) to first generate the future household vehicle holdings by type and then, through a travel-elasticity function, total personal VMT and energy consumption by type of vehicle and length of trip. For intercity travel, a 1977 base-year file of passenger miles of travel from standard metropolitan statistical area (SMSA) to SMSA was developed from the National Travel Survey and is maintained together with Bureau of Economic Analysis (BEA) population and employment data and base and forecast travel time and cost factors by mode (13). These files are input to an intercity

TABLE 1 Key Economic and Demographic Assumptions and Fuel Prices Used in the ANL-83N Forecast

Parameter	1980	1982	1990	2000	2010	Avg Annual Change, 1980-2010 (%)
Economic and demographic assumptions						
GNP (\$1982, billion)	3,053	3,056	3,978	5,065	6,275	2.43
Personal income (\$1982, billion)	2,511	2,579	3,353	4,534	6,242	3.08
Industrial production index (1982=100)	106	100	141	191	257	3.00
Median household income (\$1982)	20,750	20,170	21,850	24,240	29,115	1.14
Total population (x10 ⁶)	225.5	234	250	268	283	0.76
Total household (x10 ⁶)	80.4	83.5	101	116	125	1.54
Avg household size ^a	2.75	2.72	2.41	2.25	2.21	-0.73
Fuel prices (\$1982)						
Crude oil (\$/bbl) ^b	39.40	33.59	31.90	57.40	83.60	2.55
Gasoline (\$/gal) ^c	1.41	1.28	1.39	2.00	2.62	2.90
Diesel (\$/gal) ^c	1.16	1.14	1.29	2.03	2.79	2.97
Jet fuel (\$/gal)	1.04	1.15	0.97	1.72	2.48	2.94
Electricity (¢/kW-hr)	6.24	6.90	7.20	8.20	8.40	1.00

Note: Sources are as follows: GNP, personal income, industrial production index, Data Resources (5); population, DOE and Census Bureau (4); households, DOE (4); median household income, Census Bureau (7) for 1980 and 1982, ANL estimates for forecast years based on trends by Data Resources (5); fuel prices, DOE and Saricks et al. (4,8).

^aPopulation (excluding persons in group quarters)/household.

^bWorld oil price.

^cIncludes taxes. Assumes a constant state tax rate of \$0.09/gal in 1982 dollars, and a federal tax rate of \$0.04/gal for 1980 and 1982 and a constant \$0.09/gal (all in 1982 dollars) for 1983 and beyond.

travel demand and mode split model in which origin-destination flows for business and nonbusiness trips are based on projected travel time and cost by mode, population, employment, and hotel sector receipts.

On the freight side, base-year data from the 1977 Commodity Transportation Survey and other mode-specific sources on ton-miles of travel (TMT) by commodity sector and mode are coupled with Truck Inventory and Use Survey (TIUS) data on base-year trucks, vehicle miles, and fuel efficiency, and the output of an economic driver model. This is used to generate forecasts of commodity TMT, with intermodal shifts governed by fuel price changes and/or specific service constraints (according to L. Fowler of the As-

sociation of Oil Pipelines) (14-17). Truck TMT are converted to VMT based on historical and forecast estimates of average loads by commodity sector, and fuel consumption is computed as a function of truck VMT and forecast fuel efficiency by truck size. Rail, water, pipeline, and air freight energy consumption are computed as a function of forecast TMT and energy intensity (Btu/ton-mile) by commodity sector and mode.

Results

Tables 2 and 3 present the ANL-83N forecast of passenger and freight activity and energy consumption

TABLE 2 Projections of Transportation Activity by Mode and Submode, ANL-83N Forecast

Transportation Mode and Submode	Activity (x10 ⁹) ^a				Change, 1980-2010 (%)	
	1980	1990	2000	2010	Total	Annual
Automobile (VMT) ^b	1,111.9	1,457.0	1,622.4	1,787.3	60.7	1.6
Small	306.9	491.3	612.1	684.3	123.0	2.7
Medium	421.0	607.4	654.6	742.3	76.3	1.9
Large	384.0	358.3	355.7	360.7	-6.1	-0.2
Personal light truck (VMT) ^c	194.6	277.3	306.4	315.5	62.1	1.6
Bus (VMT)	5.8	6.9	7.8	- ^d	-	-
Commercial truck (TMT) ^e	637.5	818.5	1,046.7	1,251.2	96.3	2.3
Commercial truck (VMT) ^f	205.7	249.7	306.4	357.8	73.9	1.9
Light (VMT)	104.5	129.2	159.8	187.7	79.6	2.0
Heavy (VMT)	91.9	110.1	135.4	158.1	72.0	1.8
Rail						
Freight (TMT) ^g	934.2	1,305.7	1,830.4	2,401.1	157.0	3.2
Passenger (PMT) ^{d,h}	4.5	4.5	4.1	- ^d	-	-
Marine (TMT) ⁱ	927.1	995.1	1,076.1	1,186.4	28.0	0.8
Aviation						
Domestic passenger (PMT)	204.4	213.3	273.8	- ^d	-	-
International passenger (PMT)	63.4	84.5	113.2	- ^d	-	-
Freight (TMT)	4.3	5.9	8.5	11.2	160.5	3.2
Pipeline (TMT)	858.0	813.6	743.8	670.1	-21.9	-0.8
Natural gas	269.1	268.0	252.0	222.2	-17.4	-0.6
Petroleum	587.6	570.4	531.7	525.2	-10.6	-0.4
Coal slurry ^g	1.3	1.3	1.3	1.3	0	0

^aMode value may not equal submode totals due to rounding.

^bVehicle miles of travel.

^cIncludes mini-vans.

^dNot projected beyond 2000.

^eTon-miles of travel; trucks include some local travel.

^fIncludes government trucks.

^gPotential growth in coal slurry (i.e., throughput of slurry projects with permit applications pending) included in rail traffic.

^hInter-city only.

ⁱDomestic waterborne freight only.

TABLE 3 Projections of Transportation Energy Consumption by Mode and Submode, ANL-83N Forecast

Transportation Mode and Submode	Quads (10 ¹⁵ Btu) ^a				Change, 1980-2010 (%)	
	1980	1990	2000	2010	Total	Annual
Automobile	9.18	8.01	7.31	7.66	-16.6	-0.6
Small	2.05	2.23	2.32	2.40	17.1	0.6
Medium	3.47	3.63	3.34	3.61	4.0	0.1
Large	3.67	2.38	1.96	1.89	-48.5	-2.2
Personal light truck ^b	1.88	1.78	1.67	1.62	-13.8	-0.5
Bus	0.14	0.17	0.27	- ^c	-	-
School ^d	0.05	0.05	0.05	0.07	40.0	1.0
Transit ^d	0.06	0.09	0.10	0.11	83.3	1.9
Intercity	0.03	0.03	0.05	- ^c	-	-
Commercial truck	3.40	3.38	3.76	4.22	24.1	0.7
Light	1.01	1.02	1.08	1.19	17.8	0.5
Heavy	2.39	2.36	2.68	3.03	26.8	0.8
Rail	0.61	0.81	1.11	- ^c	-	-
Freight	0.55	0.75	1.04	1.36	147.3	3.1
Passenger	0.07	0.06	0.07	- ^c	-	-
Transit/commuter ^d	0.04	0.05	0.05	0.06	50.0	1.2
Intercity	0.02	0.01	0.01	- ^c	-	-
Marine	1.78	2.23	2.78	3.42	92.1	2.2
Domestic freight	0.39	0.42	0.46	0.50	28.2	0.9
International freight ^e	1.22	1.56	2.03	2.56	109.8	2.5
Recreational ^d	0.18	0.23	0.29	0.35	94.4	2.3
Aviation	1.58	1.61	1.73	- ^c	-	-
General aviation	0.18	0.24	0.30	- ^c	-	-
Domestic passenger	1.22	1.14	1.15	- ^c	-	-
International passenger ^f	0.14	0.17	0.19	- ^c	-	-
Domestic freight	0.04	0.06	0.08	0.11	175.0	3.3
Pipeline	0.84	0.83	0.78	0.71	-15.5	-0.6
Natural gas	0.68	0.68	0.64	0.56	-17.6	-0.6
Crude oil	0.09	0.09	0.08	0.08	-11.1	-0.4
Petroleum products	0.07	0.07	0.06	0.06	-14.3	-0.3
Coal slurry ^g	0.00	0.00	0.00	0.00	0	0
Miscellaneous vehicles ^h	0.20	0.19	0.21	0.25	25.0	0.7
Total ⁱ	19.61	18.99	19.55	21.49 ^j	9.6	0.3 ^j

^aMode values may not equal submode totals due to rounding.

^bIncludes mini-vans.

^cNot projected beyond 2000.

^dProjections from ANL (3), extrapolated to 2010.

^eU.S. sales of bunker fuels; includes foreign-flag and some military consumption.

^fFuel purchases in United States by domestic carriers; assumes 50 percent of their fuel is purchased overseas.

^gAssumes no new construction of coal slurry pipelines.

^hIncludes motorcycles, snowmobiles, and off-highway trucks (excludes farm tractors).

ⁱExcludes military consumption and all lubricants.

^jRough estimate derived by extrapolating 1980-2000 growth of modes, for which 2010 forecast is not shown.

by 10-year intervals from 1980 to 2010. For highway modes, significant improvements in fuel efficiency result in declining consumption for light-duty vehicles and only modestly rising consumption for heavy-duty vehicles despite substantial increases in VMT. This is shown most clearly in Table 4, which provides average fuel economy (in miles per gallon) and percentage of fuel economy improvement by vehicle size and fuel type for each of the forecast years. The fuel economy improvement of light-duty vehicles is more than twice that of heavy-duty vehicles, largely because of already achieved progress in response to mandated fuel economy standards, some size shifts (primarily toward the compact light truck for personal use and the small automobile), and increased diesel penetration. Between 1980 and 2010, the share of diesels in the automotive and personal light truck fleets rises from less than 1 percent to nearly 10 percent. The percentage of diesels in the commercial truck fleet increases as follows:

Truck Type	1980	2010
Light (Classes 1 and 2)	1	28
Medium (Classes 3 to 5)	2	54
Light-heavy (Class 6)	10	88
Heavy-heavy (Classes 7 and 8)	83	100

The increased penetration of diesel automobiles and personal light trucks is attributable to the characteristics of the diesels represented in the vehicle choice model that are equal in performance

(i.e., horsepower per pound), have only moderately higher maintenance and capital costs, and achieve significantly better fuel economy than their gasoline counterparts. All future diesel automobiles are assumed to be turbocharged. For commercial trucks, increases in diesel use are an input to the forecasting process and are based on historical trends in stocks and sales, fuel price assumptions, and technology forecasts from the literature (17-20).

The following are highlights of the ANL-83N forecast:

- The automotive fleet is projected to stabilize at about 40 percent small (including two-seat minicompacts), 40 percent medium, and 20 percent large (including sports and specialty models).

- By 2010, "equal performance" turbodiesels are projected to represent nearly 10 percent of automotive and personal light truck stocks, assuming a diesel fuel wholesale price somewhat higher than that of gasoline and comparable tax rates.

- With nearly flat post-1985 improvements in the efficiency of new automobiles, fuel economy is projected to rise to a fleet average of 27.7 mpg in the year 2000 and 29.1 mpg in 2010.

- Because of slower economic growth, rising fuel prices, and an aging population, post-2000 travel by private vehicles (passenger car and light trucks) is projected to grow at only 0.9 percent per year, compared with 2 percent per year from 1980 to 2000. Nonetheless, automotive energy use falls

TABLE 4 Fleet Average Fuel Economy by Vehicle Size Class and Fuel Type, ANL-83N Forecast

Size Class and Fuel Type	On-Road Fuel Economy (mpg)				Improvement, 1980-2010 (%)
	1980 ^a	1990	2000	2010	
Automobile	15.2	22.7	27.7	29.1	91.4
Small	18.7	27.6	33.2	34.7	85.6
Medium	15.2	22.4	27.2	28.4	86.8
Large	13.1	18.8	22.8	24.0	83.2
Gasoline	15.1	22.6	27.4	28.7	90.1
Diesel	21.5	31.2	36.1	38.5	79.1
Truck	9.8	13.3	14.9	15.3	56.1
Personal light ^b	13.0	19.6	23.2	24.6	89.2
Gasoline	12.9	19.3	22.7	23.8	84.5
Diesel	17.0	23.7	27.6	30.1	77.1
Commercial light (Classes 1 and 2)	14.0	17.2	20.4	21.7	55.0
Gasoline	14.0	17.0	19.3	19.9	42.1
Diesel	17.0	20.9	24.2	26.0	52.9
Medium (Classes 3 to 5)	7.0	8.3	8.9	9.3	32.9
Gasoline	7.0	8.2	8.5	8.7	24.3
Diesel	7.3	8.8	9.5	9.8	34.2
Light-heavy (Class 6)	5.8	6.8	7.6	8.0	37.9
Gasoline	5.8	6.4	6.7	6.9	19.0
Diesel	6.0	7.2	7.8	8.1	35.0
Heavy-heavy (Classes 7 and 8)	4.9	6.1	6.6	6.8	38.8
Gasoline	4.4	4.9	5.2	5.2	18.2
Diesel	4.9	6.1	6.6	6.8	38.8

^aThe low variation in historical gasoline versus diesel truck fuel economy within size classes is attributed to relatively more demanding mission requirements for diesel vehicles. With increased diesel use by vehicles with less demanding missions, average diesel fuel economy should increase and the gasoline versus diesel variation should widen.

^bIncludes mini-vans.

through 2000 as fuel economy improvements outstrip growth in travel demand.

- Assuming 1983 NEPP trends in general economic conditions and the rate of household formation, and also assuming an aging population, the forecast indicates that the number of automobiles in use should grow from 104.6 million in 1980 to 150 million by 2000 and 167.3 million by 2010. Light trucks (including mini-vans) should grow from 30.1 million in 1980 to 45.8 million by 2000 and 49.6 million by 2010. Again, changes in household demographic characteristics produce faster growth during the years 1980 to 2000 than post-2000 (1.8 and 1.2 percent annual growth for 1980 to 2000 versus 1.1 and 0.8 percent for 2000 to 2010 in numbers of automobiles and personal light trucks).

- Truck use is projected to become increasingly associated with the service sector and pickup-and-delivery portions of intermodal movements.

- Improvements in the energy efficiency of trucks--as a result of both shifts from gasoline to diesel engines and technical improvements in engines, drivetrains, aerodynamics, and rolling resistance--are projected to restrain the growth in truck energy consumption in the near-term future. In the longer term, growth will resume in the absence of more radical improvements not considered in this forecast.

- Given anticipated increases in coal production and use, continued growth in intermodalism for domestic and international shipments, and cost and service competition in a deregulated environment, rail is projected to capture an increasing share of freight traffic.

- Because of few improvements in energy efficiency, rail and maritime energy consumption are projected to grow at much the same rate as rail and maritime ton-miles.

- Excluding coal and chemicals, the production of bulk commodities (especially ores and petroleum) is projected to grow much more slowly than production of manufactured goods. Thus, rail and truck ton-miles grow faster than domestic maritime ton-miles.

- Assuming no further development of coal slurry pipelines, pipeline energy consumption is projected to decline.

- Air travel (as measured in revenue passenger-miles) is projected to grow at annual rates of 1.5 percent for domestic flights and 2.9 percent for international flights between 1980 and 2000. However, because of significant improvements in aircraft fuel efficiency (due to operational improvements and to introduction of technologies now under development in NASA's Aircraft Energy Efficiency Program), energy consumption declines by 0.3 percent annually for domestic travel and grows by only 1.6 percent annually for international travel.

The more significant macroresults of the forecast concern the growth trajectory of total consumption and the changing mix of fuels consumed by the transport sector. As can be seen in Table 3, although total consumption declines through about 1990, it then begins to rise at an increasing rate (reaching 1 percent annually between 2000 and 2010). This is largely attributable to near-constant fuel efficiency for highway vehicles. Fuel efficiency is not a high priority either among the populace or in public policy. Although energy prices rise substantially, particularly after 1990, the price shocks of the 1970s do not recur and there is no major push for fuel-efficient technology. As a result, efficiency improvements already at or very close to commercialization enter the market, but there is little further development. This relative flattening of post-2000 energy intensities can be seen in Table 4.

Figure 1 shows the changing mix of fuels consumed by the transportation sector. Gasoline (including avgas) declines sharply from nearly 65 percent of sectoral consumption in 1980 to 49 percent in 2000 and 46 percent in 2010. Diesel fuel nearly doubles its share of sectoral consumption (from 13.7 percent in 1980 to 26.9 percent in 2010) and more than doubles in quantity (from 2.8 quads in 1980 to 6.0 quads in 2010). Diesel growth is particularly strong between 1990 and 2000 as technical improvements in trucks become less of a factor, and strong coal growth increases rail diesel consumption. Jet fuel use rises only moderately--because of increased seating densities, high load factors, and new fuel-efficient aircraft--as does its share of sectoral consumption (from 10.7 to 11.8 percent by 2010, ad-

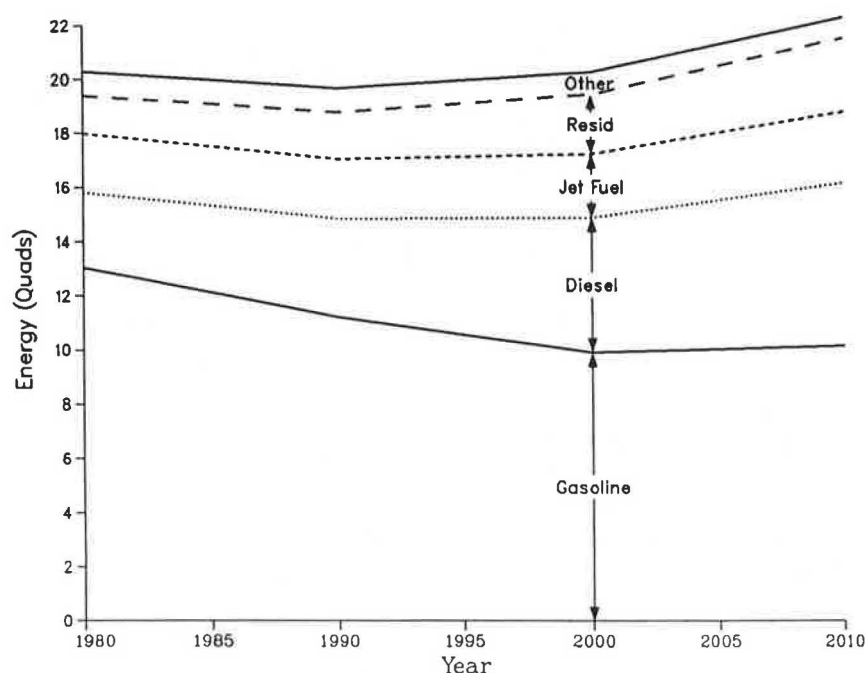


FIGURE 1 Transportation energy use by fuel type: ANL-83N forecast (all U.S. purchases, including military).

justed to include military and foreign-flag purchases in the United States). Use of residual fuel rises steadily because of increased foreign trade and no assumed improvements to maritime fuel efficiency or changes in bunkering practices (see later discussion). "Other" fuel use--primarily natural gas and electricity for pipeline compressors, and small amounts of electricity for rail passenger modes--remains stable through 2000, then declines because of a reduction in shipments of natural gas and petroleum products.

As stated earlier, the TEEMS package is driven by a combination of (a) 1983 NEPP forecasts of fuel price, general economic conditions, household formation, and energy supply, and (b) DRI's spring 1983 forecasts of personal income and economic activity of nonenergy sectors (5). In two key areas, the assumptions in these driver models combine to produce surprising results:

1. The ANL-83N forecast of personal vehicle stocks, VMT, and energy consumption is significantly greater than that of a 1981 ANL forecast that used the same methodology (3) (see Table 5 for the ANL-83N

stock forecast). The difference is due to demographics; the year 2000 population is approximately 3 percent greater in the later effort and the number of households (the most significant parameter in our models) differ by nearly 12 percent. Although a higher number of households reduces median household income (estimated from the economic aggregate, personal income), which tends to depress vehicle purchase and use, this downward effect is more than offset by the sheer number of households available to own and use vehicles.

2. In the ANL-83N forecast, rail freight activity (TMT) grows by more than 150 percent between 1980 and 2010 (a compound rate of 3.2 percent annually and rail freight energy use grows nearly as fast (3.1 percent annually). Assuming that rail maintains its current share of the freight market, one would expect rail TMT to grow at nearly the same rate as the overall economy, that is, about 110 percent (2.5 percent annually). The "excess growth" is largely attributable to (a) the 1983 NEPP coal forecast (1,286 million tons produced in 1995), which is 15 percent higher than the National Coal Association's medium-growth forecast, (b) the authors' assumption

TABLE 5 Projection of Motor Vehicle Stocks, ANL-83N Forecast

Vehicle Type and Size Class	Vehicles ($\times 10^6$) ^a				Avg Annual Change, 1980-2010 (%)
	1980	1990	2000	2010	
Automobiles	104.56	129.33	149.97	167.26	1.58
Small	28.38 (27)	42.14 (33)	56.03 (37)	63.90 (38)	2.74
Medium	38.81 (37)	52.47 (41)	58.19 (39)	66.78 (40)	1.83
Large	37.37 (36)	34.72 (27)	35.75 (24)	36.58 (22)	-0.07
Trucks ^b	34.17	44.11	50.58	56.44	1.69
Personal light	19.14	25.86	29.29	30.45	1.56
Commercial light	11.00	13.48	16.47	19.19	1.87
Medium	0.85	1.03	1.26	1.47	1.84
Light-heavy	1.68	2.03	2.50	2.93	1.87
Heavy-Heavy	1.50	1.71	2.06	2.40	1.58
Total	138.73	173.44	201.55	223.70	1.61

^aNumbers in parentheses represent percent share among the three size classes.

^bIncludes mini-vans and government vehicles.

that all coal production above the historical high of some 580 million tons will come from western sources with an average rail length of haul comparable with that of western coal in 1978, and (c) an above-average growth (the average is 2.5 percent annually) for such relatively heavy rail users as chemicals and transportation equipment manufacturers (5,15,21).

FORECAST COMPARISONS

In addition to NEPP and ANL, two other forecasts of transportation energy use have been released in the past year: the Energy Information Administration (EIA) forecast contained in the 1983 Annual Energy Outlook and DRI's latest TREND84 forecast from their spring 1984 Energy Review (22-24). The following comparisons focus on energy consumption by fuel type and by type of highway vehicle (i.e., automobile, light truck, and heavy truck) and on the technical, economic, and other factors responsible for much of the variation among the forecasts.

Consumption by Fuel Type

Table 6 compares the four energy forecasts by fuel type. With the exception of the 1983 NEPP forecast, the most striking feature of this comparison is the consensus regarding total sectoral consumption. As can be seen in Figure 2, gasoline and diesel consumption trends also stand out as areas of strong agreement (because of variations in base-year estimates among the sources, the indices shown are relative to the 1980 values reported by each source). Jet fuel consumption trends are somewhat more dispersed, partly because of differences in passenger travel demand forecasts and partly because of different assumptions regarding the introduction and penetration of new fuel-efficient aircraft. Most dispersed of all are the residual fuel trends (Figure 3), which range from a 1990 low of 56 percent of 1980 consumption in the EIA forecast to a high of 124 percent in the ANL forecast and maintain a similar spread in the year 2000. This divergence is

due to differences in modeling scope; in the ANL forecast, demand for residual fuel is solely a function of increased shipping activity, and the share of fuel purchased in the United States is assumed to remain at historical levels. In the EIA, NEPP, and DRI forecasts, shipping competes with other demands for residual fuel (most notably for power generation and refinery feedstock), and overseas purchases satisfy an increasing share of demand. Although price controls undoubtedly distorted the 1980 share of bunker fuel purchases in the United States (producing a significant but unknown amount of "double-bunkering"), the 1981 to 1983 world recession has probably exacerbated the post-1980 decline in U.S. bunker sales. It is hoped that with monthly data for 1984 indicating a firming in U.S. bunker sales, residual fuel forecasts can be revised shortly to reflect current (and presumably stable) fuel purchasing patterns (25).

Consumption by Vehicle Type

In all four forecasts, automobile energy use is projected to decline through about the year 2000, and truck energy is projected to rise continuously during the forecast period. This may be seen in Figure 4 where, again because of considerable variation in base-year estimates, consumption values have been indexed to the source's 1980 estimate. Although automobile and truck energy use show consistent trends across the four forecasts, there are major differences in rates of increase (or decrease), time frames in which rates of change begin to increase or decrease, and absolute growth over the forecast period. These differences can be attributed to variations in the respective stock and activity forecasts, price effects, and technological assumptions.

Stock Forecasts

Three of the four forecasts estimate motor vehicle stocks as an intermediate output. Because NEPP uses a stock model driven by DRI's forecast of new automobile and truck sales, the NEPP and DRI results are

TABLE 6 Recent Forecasts of Transportation Energy Use by Fuel Type, 1980-2000

Fuel Type	1980				1990				2000 ^a		
	ANL-83N	NEPP-83	EIA-83 ^b	DRI-TREND84	ANL-83N	NEPP-83	EIA-83	DRI-TREND84	ANL-83N	NEPP-83	DRI-TREND84
Gasoline	13.05		12.71	12.46	11.22		12.24	11.89	9.89		10.63
Motor gasoline	12.98	12.5	12.65	12.40	11.15	9.3	12.14	11.83	9.81	8.4	10.57
Aviation gasoline	0.07		0.06	0.06	0.07		0.10	0.06	0.08		0.06
Jet fuel	1.52 ^c	2.2 ^{d,e}	2.18 ^{d,e}	2.20 ^{d,e}	1.54 ^c	2.3 ^{d,e}	2.61 ^{d,e}	2.62 ^{d,e}	1.66 ^c	2.4 ^{d,e}	3.13 ^{d,e}
Diesel	2.77		2.78	2.55	3.61		3.54	3.58	4.96		4.91
Highway	1.98	2.0			2.58	2.9			3.59	4.1	
Rail	0.55				0.76				1.06		
Water	0.21				0.23				0.28		
Off-highway and other	0.03				0.03				0.04		
Residual fuel ^d	1.40	2.3 ^{e,f}	1.40	1.01	1.74 ^g	2.2 ^{e,f}	0.78	0.95	2.21 ^g	1.9 ^{e,f}	1.10
Natural gas	0.65	0.7	0.63	0.61	0.64	0.7	0.92	0.56	0.61	0.6	0.54
Electricity	0.24 ^h		0.01	0.01	0.24 ^h		0.01	0.02	0.24 ^h	0.1	0.02
Renewables						0.1				0.2	
Liquefied gases			0.01	0.01			0.01	0.01			0.01
Total	19.61 19.82 ⁱ	19.7	19.72	18.86	18.99 19.20 ⁱ	17.5	20.45	19.63	19.55 19.78 ⁱ	17.7	20.32

Note: Forecast energy use is expressed in quads (10^{15} Btu).

^aThe EIA-83 forecast extends only to 1995.

^b1980 estimates from DOE (24).

^cFuel purchases in the United States by domestic carriers only. Excludes military consumption.

^dFuel purchases in the United States by domestic or foreign-flag carriers.

^eIncludes military consumption.

^fIncludes nonhighway diesel fuel.

^gAssumes historic foreign-flag shares of U.S. bunker fuel sales.

^hIncludes consumption of oil pipeline compressors.

ⁱIncluding all military consumption and excluding electricity use by pipeline compressors.

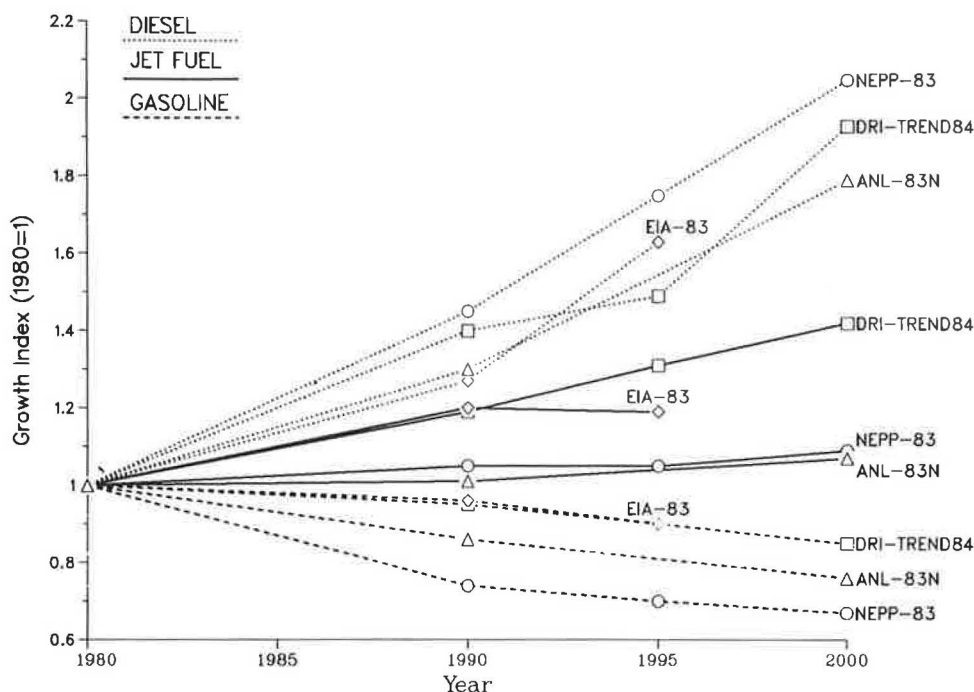


FIGURE 2 Trends in gasoline, diesel, and jet fuel demand in the transportation sector under four forecasts.

nearly identical. Small variations in the early years are due largely to differences in vehicle scrappage assumptions.

ANL's heavy truck stocks grow at much the same rate as DRI's but automobile and light truck stocks differ markedly (see Figure 5). As can be seen in Figure 6, this is largely a difference in market shares; in ANL-83N, automobiles capture a larger share of the light-duty market than in the DRI or NEPP forecasts. The similarity in light-duty stock forecasts can also be attributed to comparable eco-

nomic trends: 2.54 percent annual GNP growth for 1980 to 1995 in the EIA forecast versus roughly 2.6 percent annually between 1980 and 2000 (2.65 percent for 1980 to 1995) in the other three forecasts.

Activity Forecasts

As shown in Figure 7, ANL's forecast of truck VMT growth is the lowest, and automobile VMT growth the highest, of the four forecast efforts. This is at-

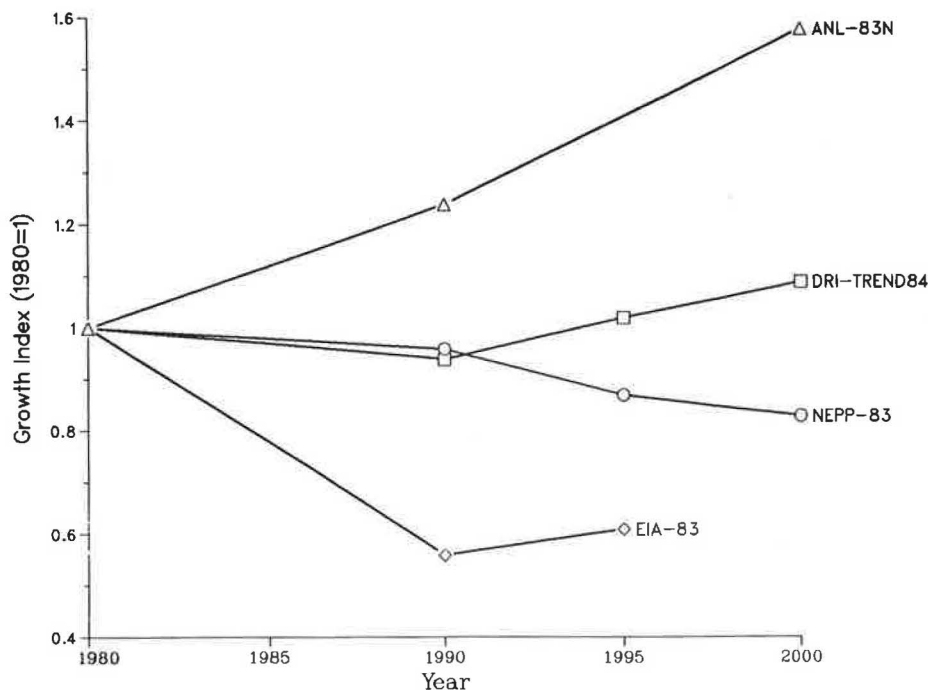


FIGURE 3 Trend in residual fuel demand in the transportation sector under four forecasts.

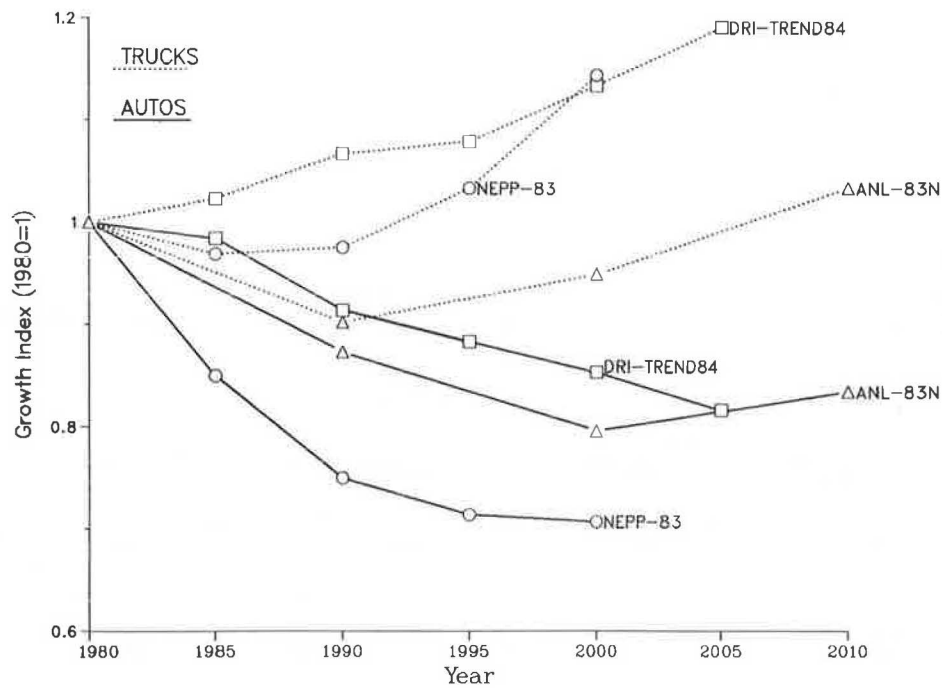


FIGURE 4 Trends in automobile and truck energy use under three forecasts.

tributable to the stock forecasts discussed earlier as well as to fairly high cost-of-travel assumptions that further depress truck VMT (see the following discussion). EIA's VMT forecasts are considerably higher than the others', partially because of technological assumptions that reduce the cost of travel and, perhaps, to relatively high price elasticities.

Technological Assumptions

Fuel economy may improve as a result of (a) shifts in consumer behavior induced by high price or un-

certain fuel availability, (b) shifts in production or marketing emphasis induced by corporate or public policy (e.g., from gasoline to heavy diesel trucks), or (c) technological development in general. All these factors appear to have influenced the four forecasts.

As shown in Figure 8, the DRI forecast assumes the lowest gasoline price in the year 2000 (about \$1.50/gal versus \$2.00/gal in the other efforts) and sustained price moderation thereafter. Given this low market incentive, DRI also assumes the lowest automotive fuel economy: 25.4 mpg in the year 2000

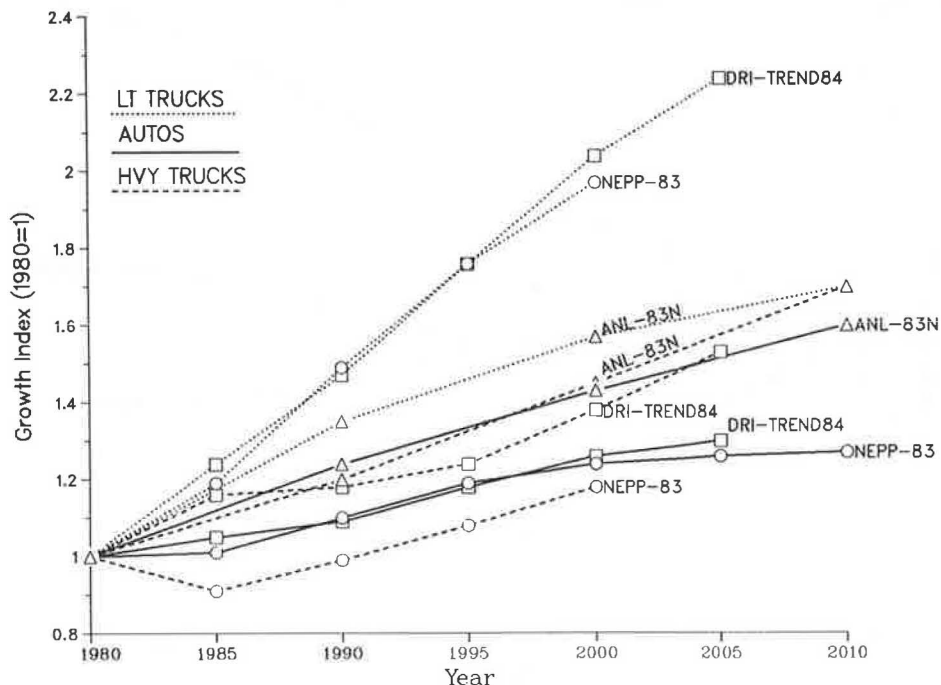


FIGURE 5 Trends in motor vehicle stocks by type under three forecasts.

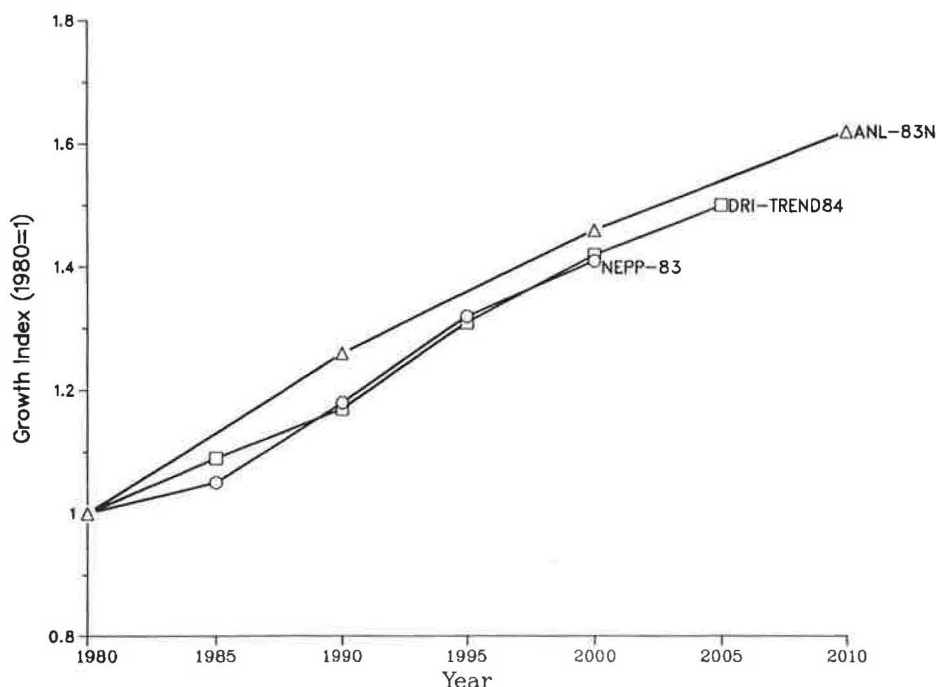


FIGURE 6 Trends in light-duty vehicle stock under three forecasts.

(see Figure 9). The combined effects of much lower-priced fuel and somewhat lower mpg produce substantially lower fuel operating costs (see Figure 10). DRI evidently assumes a fairly low price elasticity (or, conversely, the other forecasts assume a high price elasticity), because automobile and truck VMT are not appreciably higher in the DRI forecast.

At the other extreme, NEPP assumes the highest fuel economy improvement (automotive mpg rises from 15.15 in 1980 to 32.6 in 2000 and 34.3 in 2010, and truck mpg increases from 8.1 in 1980 to 14.4 in 2000), which also moderates the cost impact of rising

fuel prices. EIA assumes a fairly high mpg improvement, particularly for trucks (although automobiles rise to 27.9 mpg, trucks rise from 10.2 mpg in 1980 to 17.5 by 1995). Because the EIA forecast appears particularly sensitive to travel cost, the resulting reduction in travel costs (at least through 1990) sharply increases VMT. By contrast, with the lowest truck and nearly the lowest automobile improvement, the ANL forecast has relatively high travel costs and reduced rates of VMT growth.

With comparable fuel prices, the variation in fuel economy among ANL, EIA, and NEPP must arise

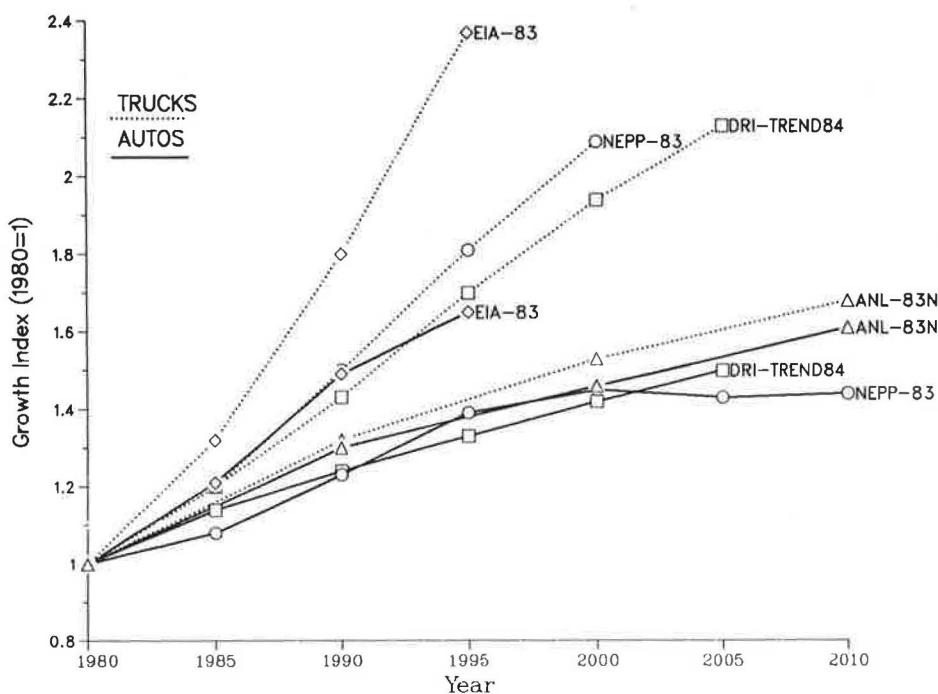


FIGURE 7 Trends in automobile and truck VMT under four forecasts.

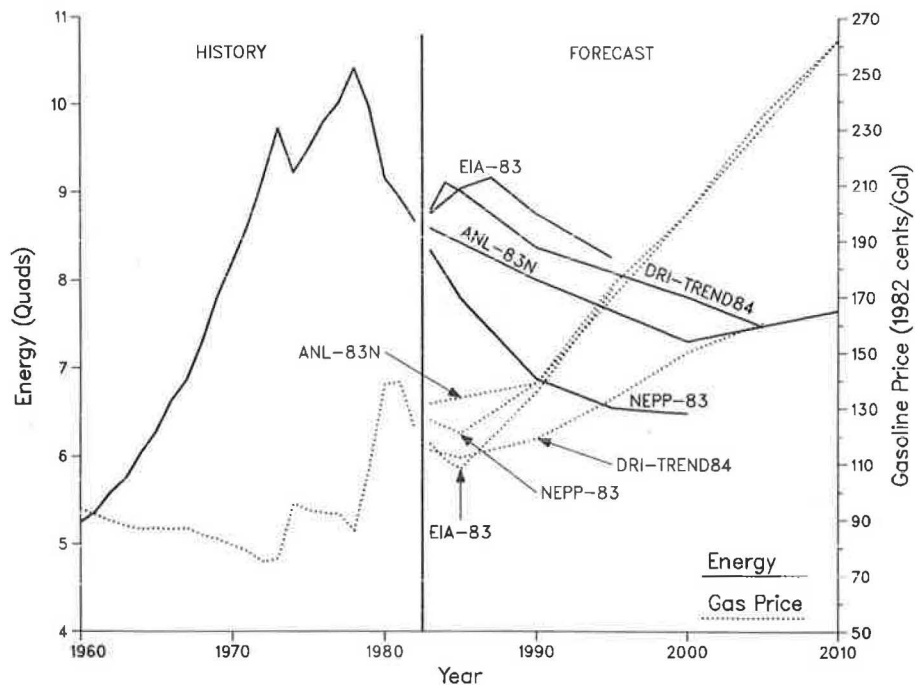


FIGURE 8 Automobile energy use versus gasoline price under four forecasts.

from assumed differences in either production and marketing emphasis or technological development. Although both are difficult to measure, one indicator of production and marketing shifts likely to influence fuel economy is the diesel share of automobile and truck fuel use. As shown in Figure 11 for those sources reporting consumption by fuel type (DRI, NEPP, and ANL), estimated diesel shares for the year 2000 vary no more than those for 1980. Diesel penetration is therefore probably not a factor in explaining mpg differences.

Rather, the rate of technological development appears to be the major influence. Although researchers agree that technological progress does not occur in a vacuum, its relationships with such other factors as fuel price, disposable income, R&D expenditures, and consumer preferences are not well understood. Recent evidence suggests some stability in consumer preferences for such vehicle attributes as interior volume and performance (which strongly influence fuel economy) and a possible trade-off between increased (or decreased) vehicle operating

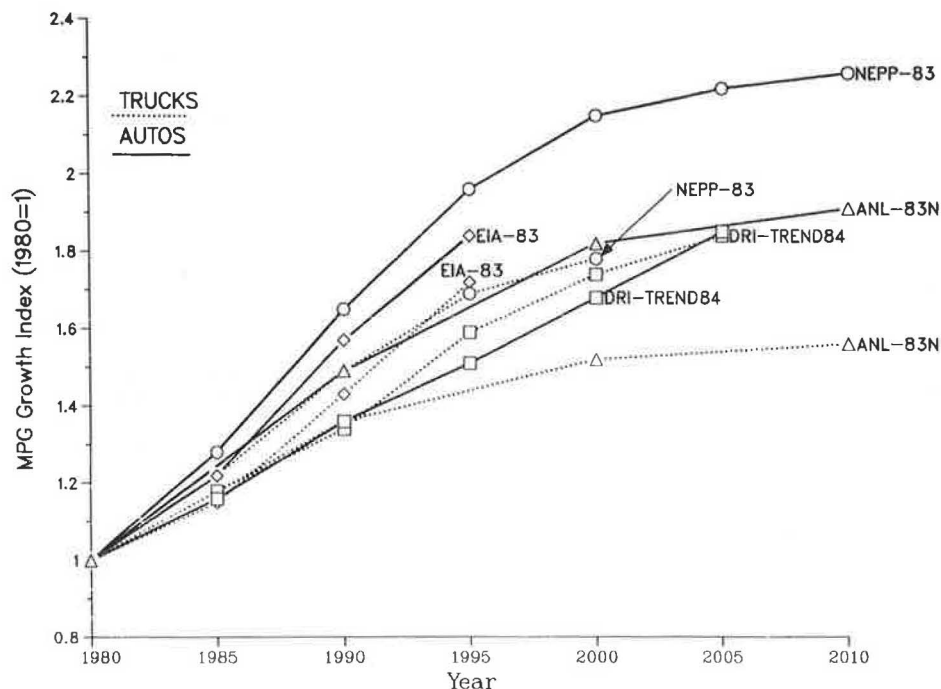


FIGURE 9 Improvements in automobile and truck fuel economy under four forecasts.

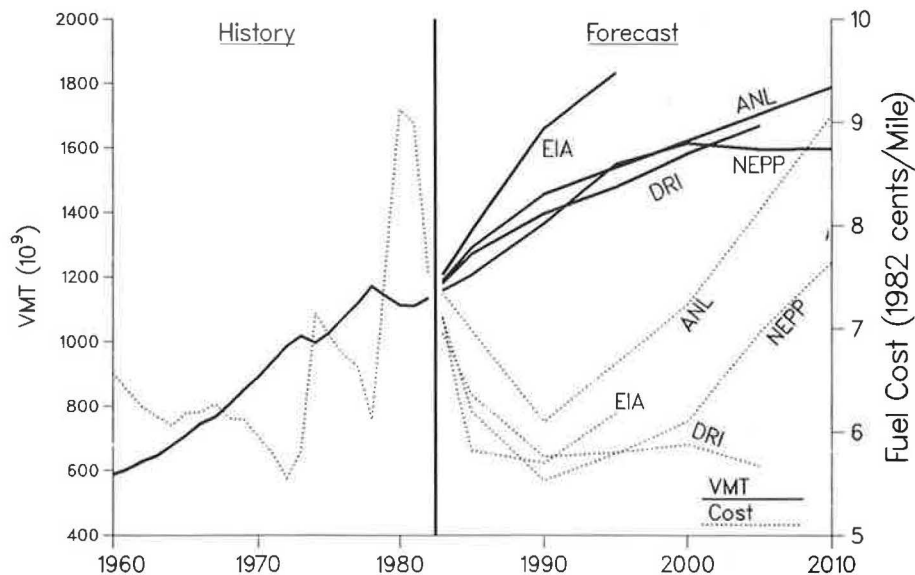


FIGURE 10 Automobile VMT versus fuel cost per mile under four forecasts.

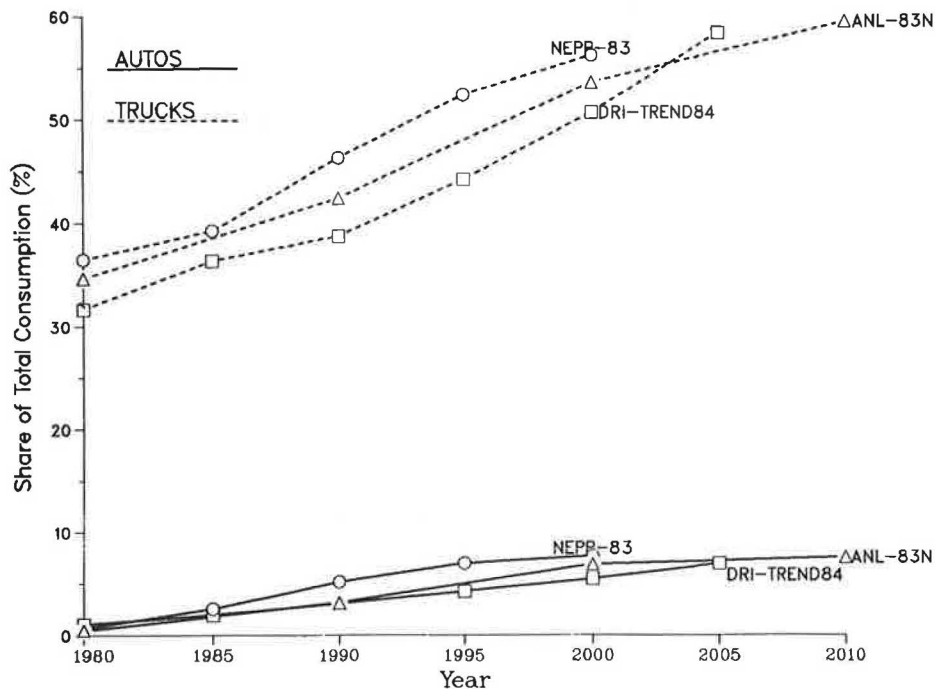


FIGURE 11 Diesel share of automobile and truck fuel use under three forecasts.

costs and purchase prices. However, these findings have not yet been incorporated into an explicit formulation of technological development as a function of fuel price and macroeconomic parameters (26,27). Although each of the efforts discussed here relies on some model of the fuel economy impact of various technological improvements and the diffusion rates of new technology into the vehicle fleet, engineering assumptions--not behavioral modes--dictate the technological "menu" that is presumed to be available in the marketplace at any given time. Thus, observed differences in the rate of technological development among the four forecasts relate solely to engineering perspective (i.e., whether and when a particular improvement is technically possible) and vehicle replacement assumptions (i.e.,

how quickly the fleet of old-technology vehicles is replaced by new-technology vehicles). Moreover, because fuel economy improvement is primarily responsible for the fuel consumption differences among the forecasts, these two factors--engineering perspective and vehicle replacement assumptions--also explain much of the overall variation among the forecasts.

CONCLUSIONS

The ANL-83N forecast indicates moderate growth in transport activity levels over the long-term future. Energy use declines through 1990 because of the continued effect of fuel economy improvements already achieved in highway vehicles and under development

TABLE 7 Selected Energy-Use Ratios, ANL-83N Forecast

Parameter	1980	1990	2000	2010
Transportation energy				
10 ⁶ Btu/capita	86.96	75.96	72.95	75.94
10 ³ Btu/\$GNP (\$1982)	6.43	4.78	3.83	3.34
Passenger transport energy ^a				
10 ⁶ Btu/capita	56.98	46.52	41.00	40.23
10 ³ Btu/passenger-mile	5.13	3.57	3.32	NA
Freight transport energy ^a				
10 ⁹ Btu/\$GNP	2.17	1.81	1.64	1.53
10 ³ Btu/ton-mile	1.61	1.42	1.35	1.32
Automobiles				
Automobiles/capita	0.46	0.52	0.56	0.59
Automobiles/household	1.31	1.28	1.29	1.34
Automobile VMT				
10 ³ VMT/capita	4.93	5.83	6.05	6.32
10 ³ VMT/household	14.06	14.43	13.99	14.30
10 ³ VMT/automobile	10.63	11.27	10.82	10.69
Light-duty VMT				
10 ³ VMT/capita	6.26	7.45	7.79	8.09
10 ³ VMT/household	17.84	18.45	18.01	18.32
10 ³ VMT/vehicle	10.48	11.05	10.67	10.56

Note: NA = not available.

^a Domestic only.

for commercial aircraft. Beyond 1990, and particularly beyond the year 2000, growth in travel demand exceeds the rate of efficiency improvement, and consumption begins to rise. As shown in Table 7, transport energy intensity continues to decline on the basis of total Btu per GNP, but by 2010 it regains its 1990 level (87 percent of its 1980 level) on the basis of total Btu per capita. Freight Btu per ton-mile and passenger Btu per capita level off at 82 percent and 71 percent, respectively, of their 1980 levels.

The ratio of automobiles per capita apparently nears saturation--increasing at a decreasing rate--whereas that of automobiles per household fluctuates. Likewise, per-capita and per-household travel rates and vehicle utilization rates also fluctuate, primarily with changing fuel costs per mile.

Compared with other recent forecasts of long-term transportation energy use, the ANL forecast is not appreciably different as far as aggregate consumption is concerned. On a disaggregate level, however, there are differences between the ANL forecast and the NEPP, EIA, and DRI forecasts in fuel type distributions, light-duty market shares (i.e., between automobiles and light trucks), and fuel economy assumptions.

The most significant difference in consumption by fuel type occurs in the residual fuel forecasts. Although the ANL forecast is a function of projected waterborne trade, the other forecasts employ a macro orientation based on supply, demand, and sectoral allocation. Differences in light-duty market shares also arise largely from orientation, demographics produce relatively greater automobile growth (and slower light truck growth) in the ANL forecast compared to the macro relationships that produce greater light truck growth in the other forecasts. Differences in fuel economy assumptions are less readily categorized, but appear to stem from the engineering models used as input to the forecasts.

The forecasting effort itself and the comparison of the four forecasts suggest the following:

- Because a forecast provides a means of making decisions, and is not an end in itself, the level of detail should be in accordance with its intended use (in the ANL case, for assisting in planning and evaluating energy conservation programs). Given its relatively specific purpose, the ANL-83N forecast

has considerably more detail on transport (including nonhighway modes not discussed here) than the other forecasts.

- The absolute numbers in a forecast are less important than the trends revealed and the sensitivity of results to key assumptions. Forecasting has risen to prominence as a strategic planning tool for (a) determining that range of conditions under which a particular decision produces desirable results and (b) thereby identifying those relatively low-risk or "robust" alternatives with desirable outcomes across a wide range of assumptions. Depending on the precise task at hand, each of the four forecasts serves this general purpose.

- The basic assumptions and other exogenous inputs in a forecast are nearly as important as the methodology used. While the forecasts discussed earlier employed significantly different methods, their aggregate results are relatively consistent because many of their economic and demographic inputs are similar. Many differences can be attributed to price (and perhaps income), elasticity of travel demand, and fuel economy assumptions.

- Technological forecasting is not well integrated into transportation energy forecasting. While the latter generally incorporates substantial socioeconomic detail, technological forecasts are largely devoid of such input. An explicit linkage between the engineering models used to forecast technological development and the socioeconomic assumptions of the forecast would surely improve the quality and consistency of results.

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