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WHY IS ENERGY USE RISING IN THE FREIGHT SECTOR?\*

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## WHY IS ENERGY USE RISING IN THE FREIGHT SECTOR?\*

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### ABSTRACT

Trends in transportation sector energy use and carbon dioxide emissions are analyzed with an emphasis on three freight modes -- rail, truck, and marine. A recent set of energy use projections is presented and freight mode energy characteristics are discussed. Transportation sector energy use, which nearly doubled between 1960 and 1985, is projected to grow more slowly during the period 1985-2010. Most of the growth is projected to come from non-personal modes (freight and commercial air). Trends in freight mode energy intensities are discussed and a variety of factors behind these trends are analyzed. Rail and marine modes improved their energy intensities during sudden fuel price rises of the 1970s. Though there is room for further technological improvement, long power plant life cycles preclude rapid penetration of new technologies. Thus, energy intensities in these modes are more likely to improve through operational changes. Because of relatively stable fuel prices, the energy share of truck operating expenses is likely to remain low. Coupled with increasing labor costs, this portends only modest improvements in truck energy efficiency over the next two decades.

### INTRODUCTION

Over the past 20 years, both the demand for freight services and the consumption of fuel by those modes conventionally considered to be freight-carrying -- namely, truck, rail, marine, and air cargo -- have grown steadily in the United States. Although freight modes now account for only 22% of the carbon dioxide emissions from the transportation sector, it is a growing share and much of the future growth in CO<sub>2</sub> emissions by the sector will come from these modes.<sup>1</sup> This paper discusses trends in CO<sub>2</sub> emissions, energy use and fuel efficiency. Historical data come from various published sources; forecasts were developed by the authors as part of a larger effort to project total transportation energy use for the Office

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of Transportation Technologies (OTT) within the U.S. Department of Energy (DOE). The forecasts use a series of disaggregate consumer choice models developed for OTT and other DOE offices and generate a wealth of detail, only a small portion of which is summarized here. In effect, the models simulate the processes whereby households select particular types of personal passenger vehicles and shippers select particular transportation modes to transport their goods or deliver their services. Key variables include exogenous forecasts of vehicle and modal attributes, retail fuel prices, economic output and distribution, commodity densities, and demographic trends. See Ref. 2 for a further discussion of these inputs, and descriptions of the models and their underlying theory.

### TRENDS IN ENERGY AND CO<sub>2</sub> EMISSIONS

Total transportation energy use, which nearly doubled between 1960 and 1985, is expected to grow only a third as fast between 1985 and 2010.<sup>2,3</sup> Trends in demographics and vehicle fuel efficiency are expected to constrain near-term growth in fuel consumption by personal vehicles. For non-personal vehicles (freight modes and commercial aircraft), the outlook is somewhat different. The economic and demographic data on which the recent forecasts<sup>2</sup> are based show shifts in the U.S. economy and continued growth in disposable personal income. These trends should spur fuel consumption in non-personal transportation while modest improvements in vehicle fuel efficiency would provide little relief. As a result, fuel consumption by freight modes is expected to increase by over 50% between 1985 and 2010, and total energy use by non-personal vehicles should surpass that for autos and other personal vehicles by 2005. (Fig. 1)

Figure 2 shows both the long-term historical trend and our baseline forecast of energy consumption by transportation mode. Viewed in this manner, the 1973-74 and 1979 oil crises appear as clear breaks in the trendlines for automobiles. Figure 3 indexes the data, thereby showing growth (or decline) relative to each mode's energy use in 1970. Over this 40-year time frame, consumption by light duty vehicles (i.e., autos and light trucks) grows 44% (only 11% from 1990 to 2010), while consumption by rail and marine (i.e., barges, coastal and Great Lakes shipping, and U.S. fuel purchases for international shipping) modes grows by nearly 70%. Energy consumption by air mode (i.e., domestic air carriers and U.S. fuel purchases by international carriers) and heavy duty highway vehicles (i.e., buses and trucks over 10,000 lb gross vehicle weight) provides an even sharper contrast, with air more than doubling and heavy duty vehicles more than tripling their fuel use over the 40-year time frame.

Disaggregating modal consumption by fuel type, emissions of carbon dioxide may be estimated by applying standard carbon-release rates. Figure 4 displays the resulting trend. Again, diesel and jet fuel (used by trucks and aircraft) account for most of the growth in CO<sub>2</sub> emissions. (Note that the baseline forecast includes no alternative fuels use, and that values shown include CO<sub>2</sub> emissions from fuel processing and transportation, as well as combustion.)

## FUEL ECONOMY AND ENERGY INTENSITY

### Data

Energy intensity, or Btu/ton-mile, may be computed from various time-series data sets of industry associations, government agencies or private groups. The Transportation Energy Data Book published by Oak Ridge National Laboratory is also a source.<sup>4</sup> For rail and marine modes, ton-miles and fuel use are routinely reported and energy intensity is a relatively straightforward calculation.<sup>5-8</sup> Because of inconsistencies in the data, however, trends are not always what they seem. For example, in the 1980s many Class I railroads\* spun off their regional and local operations into independent short lines. Operations on these typically lower-volume tracks had been included in the totals reported for Class I railroads. Thus, some of the apparent improvement in rail energy intensity may be due to a reporting change. Likewise, because Alaskan oil development greatly increased the share of domestic maritime traffic represented by relatively efficient coastal tankers, maritime energy intensity should not be aggregated across area of operation.

For trucks, the data are even less reliable. Transportation Policy Associates has estimated domestic intercity ton-miles of travel (TMT) by truck (both ICC-regulated and non-regulated) since 1950.<sup>9</sup> Data for ICC-regulated trucks are obtained from ICC reports; data for non-ICC trucks are estimated using comparable data relating to vehicle-miles of travel and average loads (i.e., tons/vehicle-mile) of contract/specialized ICC trucks as reported to the ICC.<sup>10,11</sup> In effect, Transportation Policy Associates assumes non-ICC trucks share the same characteristics as contract/specialized ICC trucks, an assumption that may or may not be correct.

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\* Railroads with annual operating revenues above a threshold set by the Interstate Commerce Commission (ICC). In 1988, that threshold was \$92 million.

Air freight data are also problematic. Because much cargo is carried in the lower hold or "belly" of passenger aircraft, ton-miles must be disaggregated by aircraft type -- passenger or all-cargo. To our knowledge, no such consistent, disaggregated time-series data exists. Thus, the following discussion excludes air freight.

### Rail Modes

Since 1970, railroads appear to have improved their energy intensity by over 30%. While some of this improvement may be attributed to technological factors, the operational efficiencies wrought by mergers and consolidations, changes in work rules and the mix of traffic, and the increased prevalence of unit trains were at least as important. Some of these factors, for example, shifts from boxcars to piggyback cars, tend to reduce fuel efficiency since the ratio of load to gross weight may decline; other factors -- like dedicated piggyback services, double stacking, and unit trains -- tend to increase fuel efficiency. Deregulation of the rail freight industry also enhanced carriers' ability to abandon marginally profitable routes, to restructure operations, and, in many cases, to upgrade equipment. As mentioned above, many low-volume routes were reorganized into regional or local railroads, which are not included in national statistics. Hence, reporting differences could also have been a factor.

Rail power units that are in use now employ relatively old technologies. The technology picture is not expected to change much over the forecast period since the majority of rail power units are relatively new. A manufacturer exchange program, in place from the mid-1970s through mid-1980s at General Motors' Electromotive Division, caused a turnover of power units. Under that program, attractive pricing encouraged railroads to replace rather than rebuild existing power units. Many locomotives with older two-stroke engines were replaced with current technology two-stroke units. However, the program reduced the potential for further improvement in energy intensity as replacement demand is likely to be depressed for some time. Even though locomotives with energy-efficient four-stroke engines are now possible<sup>12</sup>, long locomotive life spans (approximately 20 years) and a relatively young fleet, are likely to slow their penetration; technological improvements would require upwards of 20 years to produce a discernible impact. While there is plenty of historical precedent for rapid, dramatic technological changes in rail equipment (e.g., shifts from steam to diesel engines, from hand brakes to air brakes, and from smaller to larger engines to power longer, heavier consists), the base case contains no precipitating policy or event to induce such change. Thus, operational improvements are assumed to be the principal source of future efficiency gains. While research is assumed to continue on methods to use coal, residual oil,

and relaxed-specification diesel oil in medium-speed diesel engines, alternative fuels are not considered in the baseline scenario.

### Marine Modes

As it was for railroads, the energy intensity of inland marine modes (i.e., towboats and Great Lakes vessels) has improved substantially since 1970. In the future, little change is anticipated in either the fuel consumption or energy efficiency of waterborne modes, since long vehicle life cycles and low fuel costs (as a portion of total operating costs) provide little incentive for fuel efficiency improvement.

The past improvements in energy intensity are attributable to transport of large volumes of Alaskan oil and increase in domestic coastal traffic because oil tankers and coastal vessels have relatively more efficient power units and duty cycles than push/tow boats operating in inland waterways. The forecast scenario assumes steady declines in Alaskan oil output, so this beneficial effect is assumed to slowly erode over time.

Marine engines are two-stroke diesels with long operating lives. Current-technology four-stroke engines with higher stroke-to-bore ratios may be able to reduce fuel use; however, short of wholesale engine replacement (which could take up to 30 years), little improvement is foreseen. Some other technological and operational improvements (see Ref. 2) could lower the energy intensity but are deemed not to be cost effective under the forecast scenario fuel prices.

### Heavy Trucks

According to the Federal Highway Administration, the fuel economy of the entire fleet of heavy-duty combination (i.e., tractor-trailer) trucks rose from 4.78 mpg in 1970 to 5.34 mpg in 1989, an improvement of only 12%.<sup>10</sup> While fuel economy increased steadily in the 1970s, it declined somewhat in the 1980s. Many factors contributed to this lack of progress, including inefficient fleet management; low load factors (including an excess of empty backhauls); poor driver training; increased urban congestion; higher speed limits on rural interstate highways; shifts within the stock of heavy trucks toward larger, less fuel-efficient vehicles; disproportionate growth in travel by these larger vehicles; and slow turnover of older, less fuel-efficient rolling stock.

Expressed in terms of energy intensity, the truck picture is even more discouraging. As shown in Fig. 5, while the average energy intensity of railroad and inland waterway operations declined by approximately a third since 1970, the energy intensity of intercity or line-haul trucks rose by nearly 40% over this time frame.

Unlike passenger cars, whose passenger and freight load is a small percentage of gross operating weight, the load of heavy trucks is large relative to the gross weight of the vehicle, and reductions in tare weight are as likely to permit additional loading as to improve fuel economy. Thus, while weight reduction still offers substantial opportunity for improving the fuel economy of light duty vehicles, it is not as promising for heavy trucks. Rather, the fuel efficiency of heavy trucks is expected to improve from continued advancements in engine technology (primarily higher torque/lower rpm engines) better engine/drivetrain matching, and more highly integrated aerodynamic designs. While increased penetration of off-the-shelf conservation measures like low profile tires and electronic engine and transmission controls should provide some benefit, recent data suggest the impact may be quite modest.

Penetration of the less costly of these measures was first spurred by sudden increases in the price of fuel during the 1970s, and has continued because of diesel fuel and road use tax increases in the 1980s. According to the 1987 Truck Inventory and Use Survey (TIUS), 20% of all Class 8 trucks (i.e., those operating at gross combination weights above 33,000 lb) were equipped with aerodynamic devices, 14% had wide axle/drive ratios, 13% had fuel economy engines, and 6% had radial tires.<sup>13</sup> However, the resulting improvements in on-the-road fuel economy were quite modest. In 1987, the average Class 8 truck with no energy conservation devices got 5.2 mpg, while the average truck equipped with a host of devices and other modifications to conserve fuel (e.g., aerodynamic devices, axle ratio changes, a high torque-rise/low rpm engine, radial tires, a road speed governor, variable fan, engine retarder, and an electronic vehicle monitoring system) got 6 mpg, an improvement of only 15.3%. Moreover, when controlled for vehicle age, it appears that the presence or absence of conservation devices had little effect on fuel economy. Vehicle age -- a variable which includes improvements in engine and drivetrain technology, in aerodynamic design, and presumably in maintenance and proportion of duty cycle in line-haul operation -- was far more significant. The data show not only that many energy conservation devices provide little or no fuel economy improvement, but some combinations of devices actually reduce fuel economy. There are several explanations for the apparently poor performance. Perhaps truck buyers are not specifying the most fuel-efficient combination of devices for their vehicle's mission. Perhaps

individual devices are not performing as claimed. Alternatively, an increasing share of "base" vehicles are entering service with factory-equipped devices that are so transparent to truck buyers that they are unaware of them.

Because of this relatively disappointing impact, our projections of efficiency improvements through implementation of conventional technologies are less optimistic for heavy-duty trucks than for passenger cars. Over the next 20 years, another 12% improvement in fleetwide fuel economy -- from continued advances in aerodynamics, increased penetration of electronic engine and transmission controls, and improved tires and lubricants -- is expected. Although individual new vehicles may achieve far greater improvements, the combination of a "less-than-ideal" operating environment and continued tight profit margins is likely to depress the average fuel economy of the truck fleet.

## FACTORS AFFECTING TRUCK ENERGY INTENSITY

Virtually all the above-noted increase in truck energy intensity occurred between 1960 and 1980. These two decades coincide with major structural changes in the economy and dramatic oil price shocks, as well as continued increases in urban traffic congestion. Deregulation of the transportation industry occurred somewhat later and, thus, was probably not a factor (although it may be argued that increased modal competition prevented truck energy intensity from deteriorating further).

### Economic Factors

Between 1960 and 1980, the economy underwent major structural change. The service sector became an even larger component of output, imports of manufacturer and consumer goods grew phenomenally, the composition of industrial output shifted toward lower-density commodities, and the cost of capital grew to historically high rates.

#### 1. Services

Continuing a much longer trend, the service sector rose from 26% of GNP in 1960 to 31% by 1980 (Fig. 6). As a result, physical output -- ton-miles (assuming no change in average length of haul) and vehicle-miles (assuming no change in average load) -- should have grown less than the total economy. However, vehicle-miles (VMT) grew considerably faster (3.7% per year). Much of this growth can be attributed to fast-growing service industries, such as pizza and small package delivery services; lawncare,

home and office cleaning and other maintenance services; and communications, all of which rely on trucks, mainly light trucks. Given the increasing service orientation of the economy, this suggests that ton-miles may be an increasingly inaccurate indicator of truck activity, and Btu/TMT may be an equally inaccurate measure of efficiency. However, because ton-miles are commonly used to describe activity for other freight-carrying modes, the metric permits analyses of modal competition. Miles per gallon is certainly a potential substitute, but since it takes no account of load factors, one can argue that it is too coarse a metric.

## 2. Imported Goods

Over this time frame, the value of imported goods tripled as a share of GNP, rising from 2.95% in 1960 to 9.06% in 1980, while exports doubled (rising from 3.96% to 8.24%, see Fig. 6). As imports displaced domestic production, fewer of the inputs to the production process came from traditional, domestic sources, and finished goods began to compose a larger share of ton-miles. Because of their higher value and susceptibility to damage in shipment, finished goods generally require more elaborate packaging. This reduces not only density (i.e., weight per unit volume) but also average load as trucks quite often as not "cube out" before they "weigh out". This is consistent with trends shown in Transportation Policy Associates' data, which provide the basis for Fig. 7. Despite increased weight limits, the data show that the average load of combination trucks dropped by a third between 1970 and 1980. Less-than-truckload (LTL) trucks\* accounted for all of this drop, possibly due to cubing out. Since the average load of truckload (TL) trucks rose slightly through 1980, the data suggest two disparate trends -- namely cubing out in LTL trucks and weighing out in TL trucks.

All else equal, increasing the share of total goods movement represented by imported goods should also increase average length-of-haul and, because a relatively longer portion of this increased length-of-haul is linehaul, the net effect should be improved energy intensity. As shown in Fig. 8, between 1970 and 1980, average length-of-haul rose for all freight modes. Although the average for LTL trucks rose the most (34%), the average for inland waterways and railroads also rose (by 23% and 20%,

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\* LTL trucks typically carry multiple loads, each generally under 10,000 lb, under separate waybills.

respectively).<sup>\*</sup> However, as noted above, longer lengths-of-haul did not improve truck energy intensity, at least not on an overall modal basis.

### 3. Commodity Density

Relatively stronger growth in low density commodity sectors like plastics and electronics (as compared with steel and agricultural products, for example) is another key factor behind cubing out. So, too, is the continued trend toward materials substitution -- not just in vehicles, but in virtually all consumer goods.<sup>‡</sup> (See the following discussion on load composition.)

### 4. Cost of Capital

High inflation and historically high real interest rates also affect truck energy intensity. In 1960, the prime rate was 4.82%, with inflation roughly 1.6% according to the implicit price deflator; by 1980, the prime stood at 15.27%, with inflation roughly 9.1%.<sup>15</sup> Since the high cost of capital encourages firms to minimize capital expenditures, the immediate effect is a tendency toward longer vehicle replacement cycles, increased leasing, and/or more intense equipment utilization. Between 1963 and 1980, the average utilization of combination trucks rose 15% (from 42,232 to 48,472 miles as shown in Fig. 9).<sup>9</sup> Between 1980 and 1990, this average rose another 24%, to over 60,000 miles.<sup>10</sup> Freed from regulatory constraints, the utilization of rail freight cars rose an even more dramatic 45% between 1980 and 1988 (see Fig. 9).<sup>7</sup>

While increasing equipment utilization improves productivity, it does not necessarily improve energy intensity. This is not surprising, since equipment rents, depreciation, and purchased transportation typically exceed fuel as a percentage of operating expenses<sup>7,16,17</sup> (see Fig. 10). Thus, truckers generally have more incentive to improve the productivity of their equipment dollar than their fuel dollar. Figure 10 also displays expense distributions for rail and air modes. Surprisingly, for both truck and rail modes, the fuel share of operating costs is below 10%. For air, the fuel share is considerably higher, presumably a key factor behind airlines' greater tendency to adopt energy conservation measures.

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<sup>\*</sup> It is unclear why average loads on inland waterways have risen. Presumably, individual barges are more heavily loaded. Part of the increase in rail loads may be due to the exclusion of local and regional movements.

<sup>‡</sup> For example, according to the Aluminum Association's Automotive and Truck Committee, the average use of aluminum in cars increased about 65% between 1974 and 1984 (Ref. 14).

### Traffic Congestion

Traffic congestion may be a major factor behind increased truck energy intensity. As shown in Fig. 11, nearly 70% of urban interstate mileage and roughly 45% of peak traffic volume are congested in the peak hour.<sup>10</sup> For autos, much of the discrepancy between EPA-test and on-the-road fuel economy may be due to congestion.<sup>18,19</sup> The same may be true for trucks, especially those engaged in the distribution portion of intermodal services. In 1989 approximately 25% of rail car loadings were trailers or containers.<sup>7</sup> Assuming that the majority of these intermodal trips entail some urban pickup and delivery, traffic congestion should increase the energy intensity of intermodal trips. Because it is not clear whether the truck portions of such trips are being correctly accounted for in the data, increased intermodalism may be another factor behind the apparent increase in truck energy intensity.

### Load Composition

As mentioned above, loads of lower density commodities often cube out, while loads of higher density commodities weigh out. Thus, even though *average* loads may be declining, an increasing number of trucks are operating with very heavy loads. This may be seen in Fig. 12, which plots trends in the percent of traffic volume and axle loadings on rural interstates by two categories of heavy trucks (i.e., those with four or fewer axles, and those with five or more axles). Between 1970 and 1980, the heavier of the two classes rose from 8 to 14% of traffic volume and from 74 to 91% of axle loadings.<sup>9</sup> Meanwhile, the lighter of the two truck classes stayed at roughly 5% of traffic volume but dropped from 24 to 7% of axle loadings. This corresponds with TIUS results showing a bimodal distribution in truck loads and utilization -- i.e., some heavy trucks are extremely productive, carrying very heavy loads and operating far more than 100,000 miles per year, while the majority are lightly loaded and utilized.<sup>12</sup>

### Fuel and Other Costs

The increase in truck energy intensity came at a time when the price of diesel fuel was rising relative to gasoline.<sup>8</sup> Thus, fuel price was probably not a factor on an overall modal basis, although it no doubt affected the purchase decisions of individual firms. As stated earlier, labor and equipment costs account for a higher portion of average truck operating expenses than does fuel. Since labor alone represents 51% of truck operating expenses,<sup>18</sup> popular cost cutting strategies include switching from union to non-union personnel; reducing crew sizes, turnover and absenteeism; and relying on independent contractors in place of employees. Partly because of this cost-cutting and partly because of a general driver shortage, firms are placing an increasingly high priority on attracting and retaining good drivers.

Thus, new trucks are being equipped with more driver amenities like air conditioning in both cab and sleeper compartments, sound systems, improved suspensions, microwave ovens, and automatic transmissions. While the resulting loss in fuel efficiency has not been quantified, 1000 lb of driver amenities could easily exact a penalty of 0.1-0.2 mpg.

## CONCLUSIONS

Most of the increase in transportation energy use that occurred over the past 30 years came from growth in commercial aviation and heavy trucks. Of all transportation modes (freight or passenger), heavy trucks experienced the fastest growth, tripling their energy use between 1960 and 1990. Because this trend is expected to continue, non-personal transportation modes are expected to consume more energy than autos and light trucks by the year 2005.

Over the past two decades, the energy efficiency (or mpg) of the heavy truck fleet has improved relatively little, while the energy intensity (Btu/TMT) has increased. A variety of factors are to blame, including traffic congestion, tight profit margins, driver behavior and other operating constraints, shifts in the composition of economic output and truck loads, and relatively high-cost labor and equipment and low-cost fuel. Fuel-conserving devices appear to have made little impact on improving the efficiency of heavy trucks, although newer vehicles presumably incorporating advancements in engines, transmissions and aerodynamic design are approximately 15% more fuel efficient than older models. Because of these modest gains in fuel efficiency, increases in miles traveled have produced and will continue to produce near-comparable increases in fuel use.

Despite inconsistent data, freight railroads appear to have made considerable progress in streamlining their operations and improving energy intensity. This trend is essentially complete for the near-term.

Aside from increased coastal traffic due to North Slope oil development, the energy consumption characteristics of domestic waterborne commerce have been relatively stable despite increase in average length of haul. This trend is expected to continue.

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- Figure 1** Transportation Energy Use by Personal vs. Commercial Modes, 1960-2010
- Figure 2** Transportation Energy Use by Mode, 1960-2010
- Figure 3** Indexes of Energy Consumption by Mode (1970 = 1)
- Figure 4** Carbon Dioxide Emissions by Type of Transportation Fuel, 1965-2030
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- Figure 12** Shares of Traffic Volumes and Axle Loadings on Rural Interstate Highways by Trucks with Five or More vs. Fewer Axles, 1970-1989

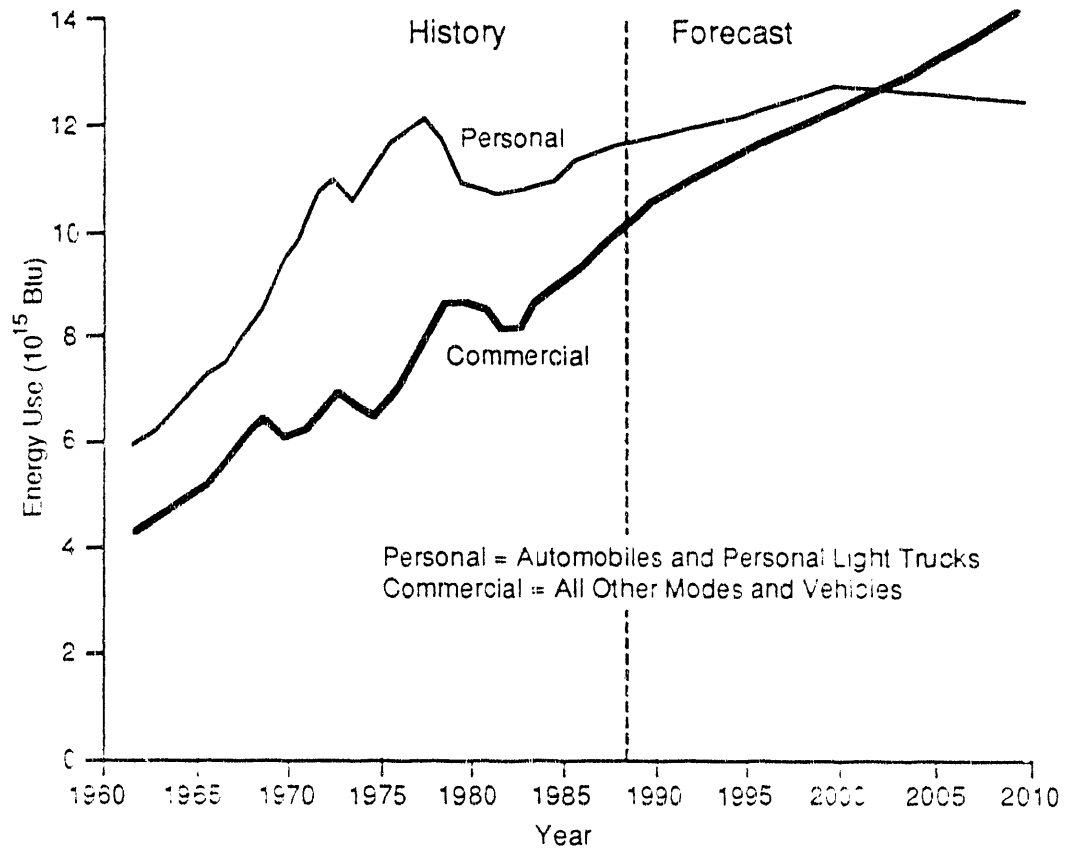


Fig. 1

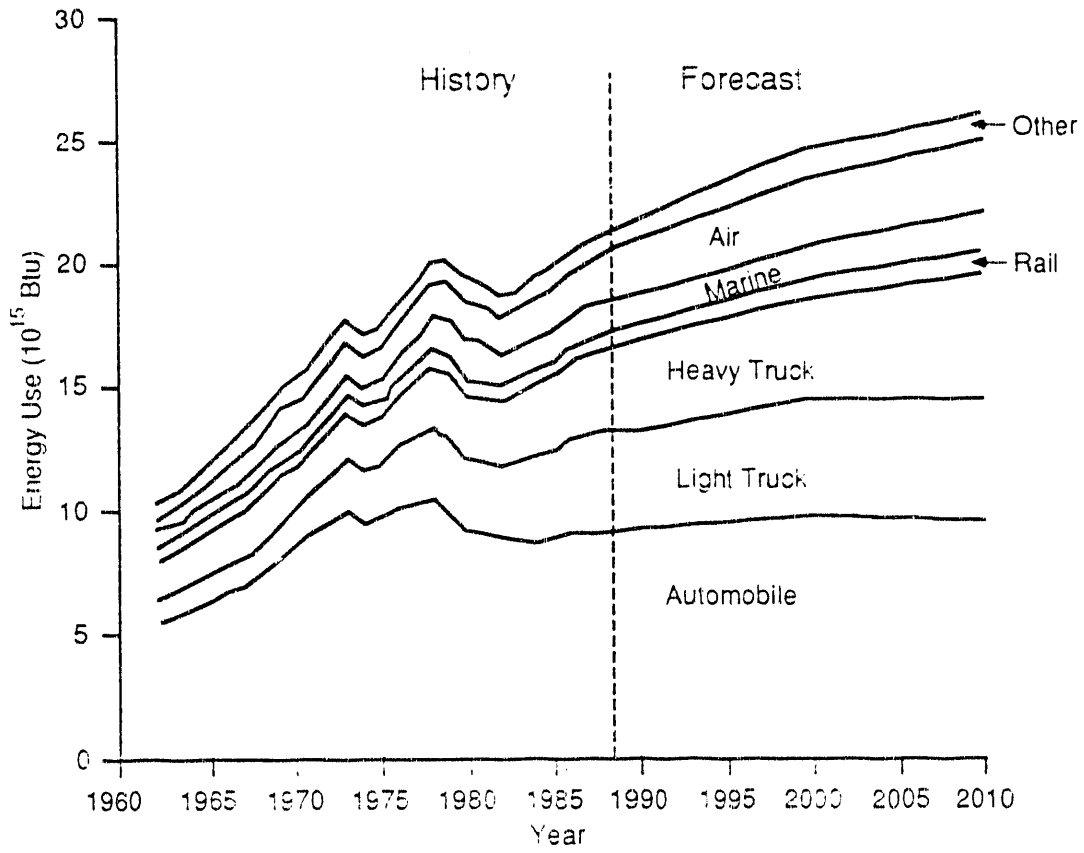


Fig. 2

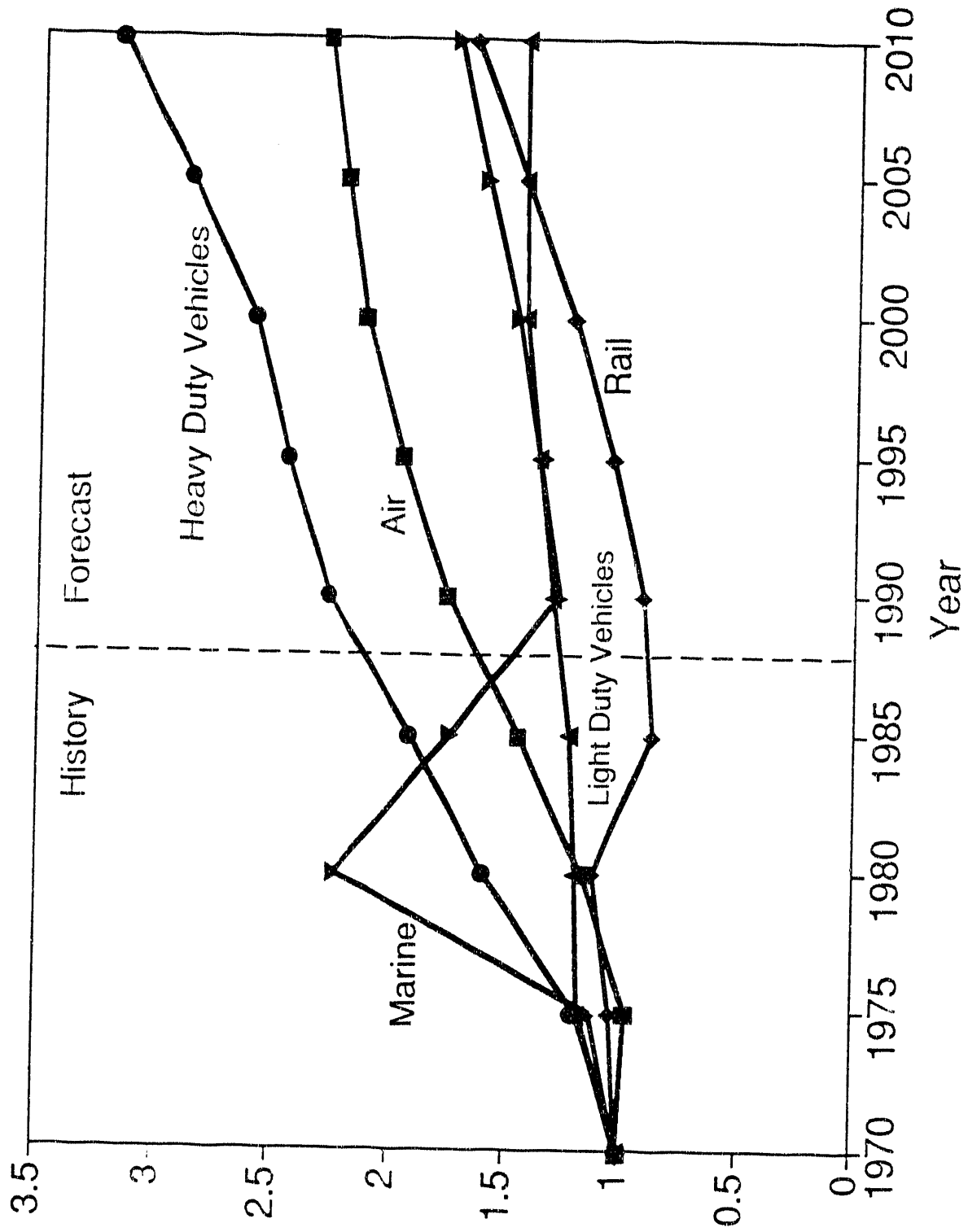


Fig. 3



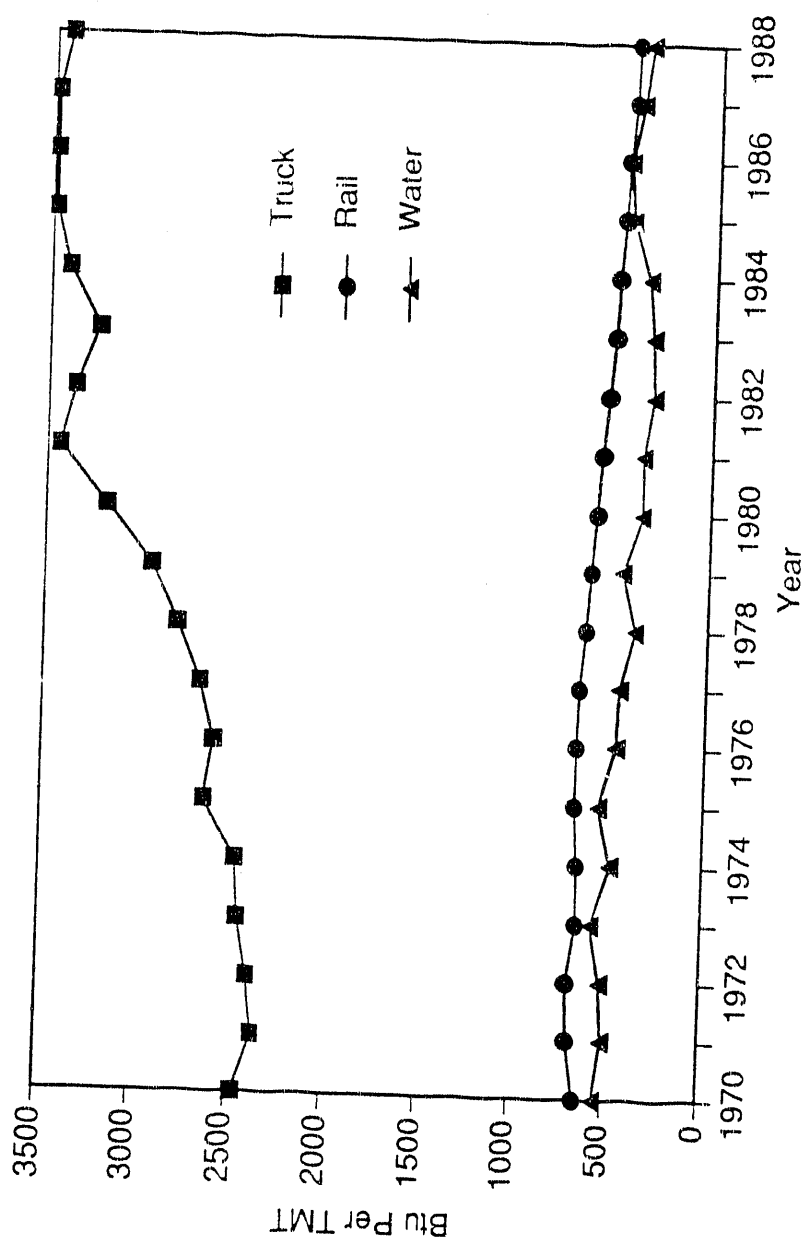


Fig. 5

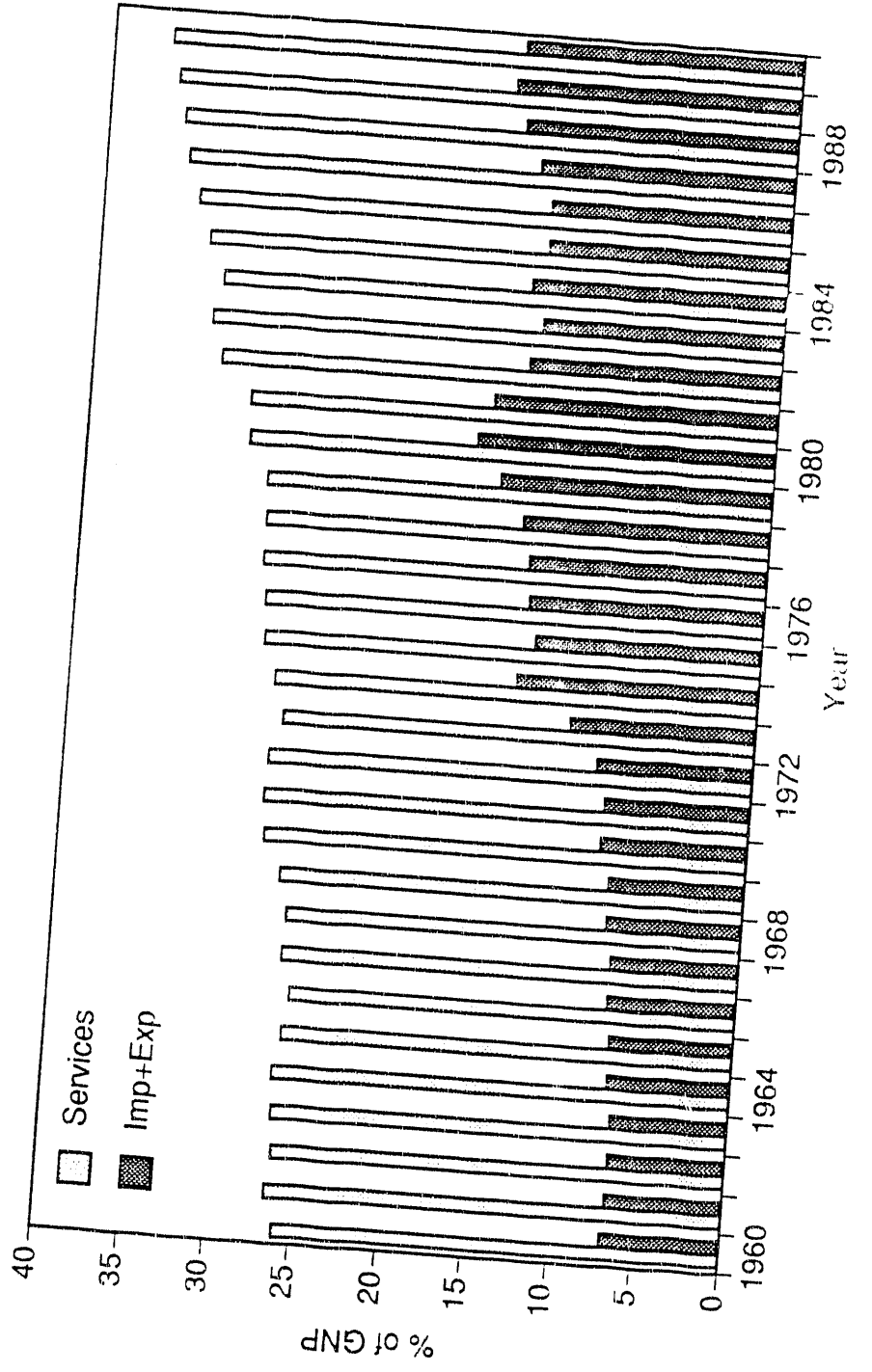


Fig. 6

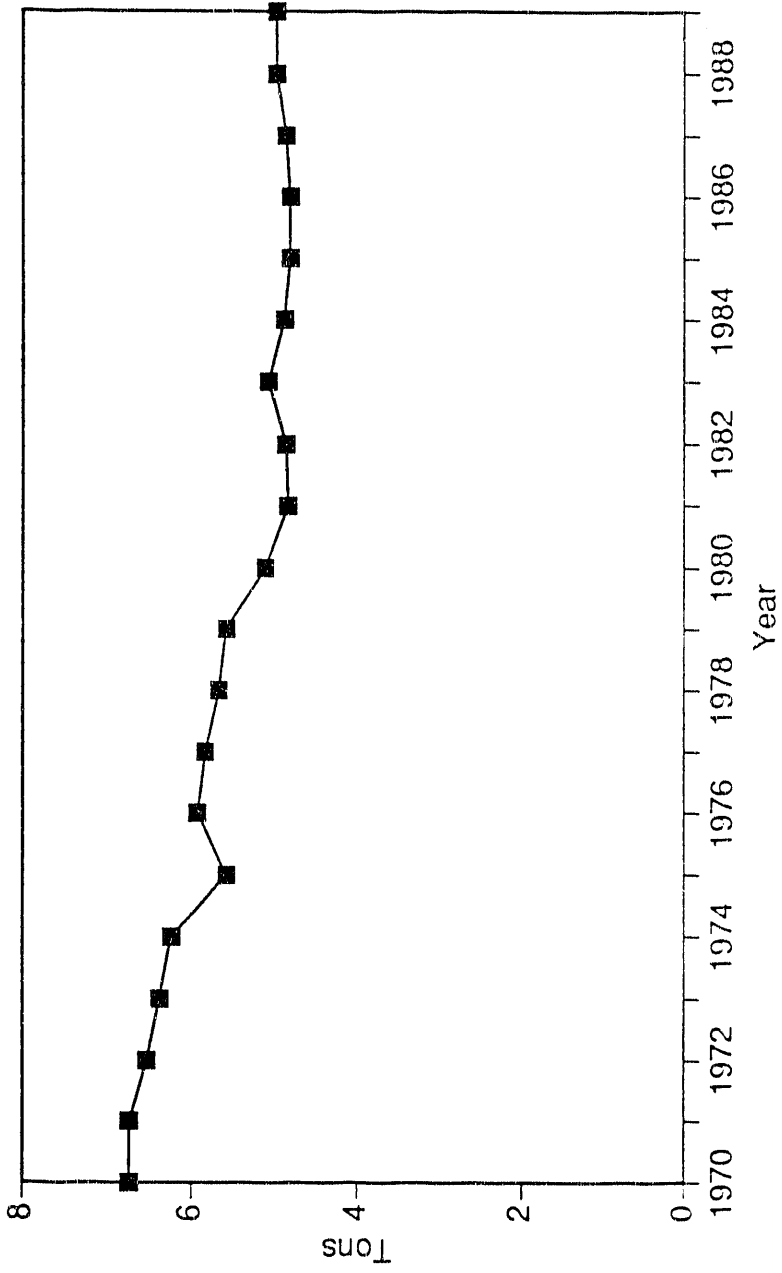


fig. 7

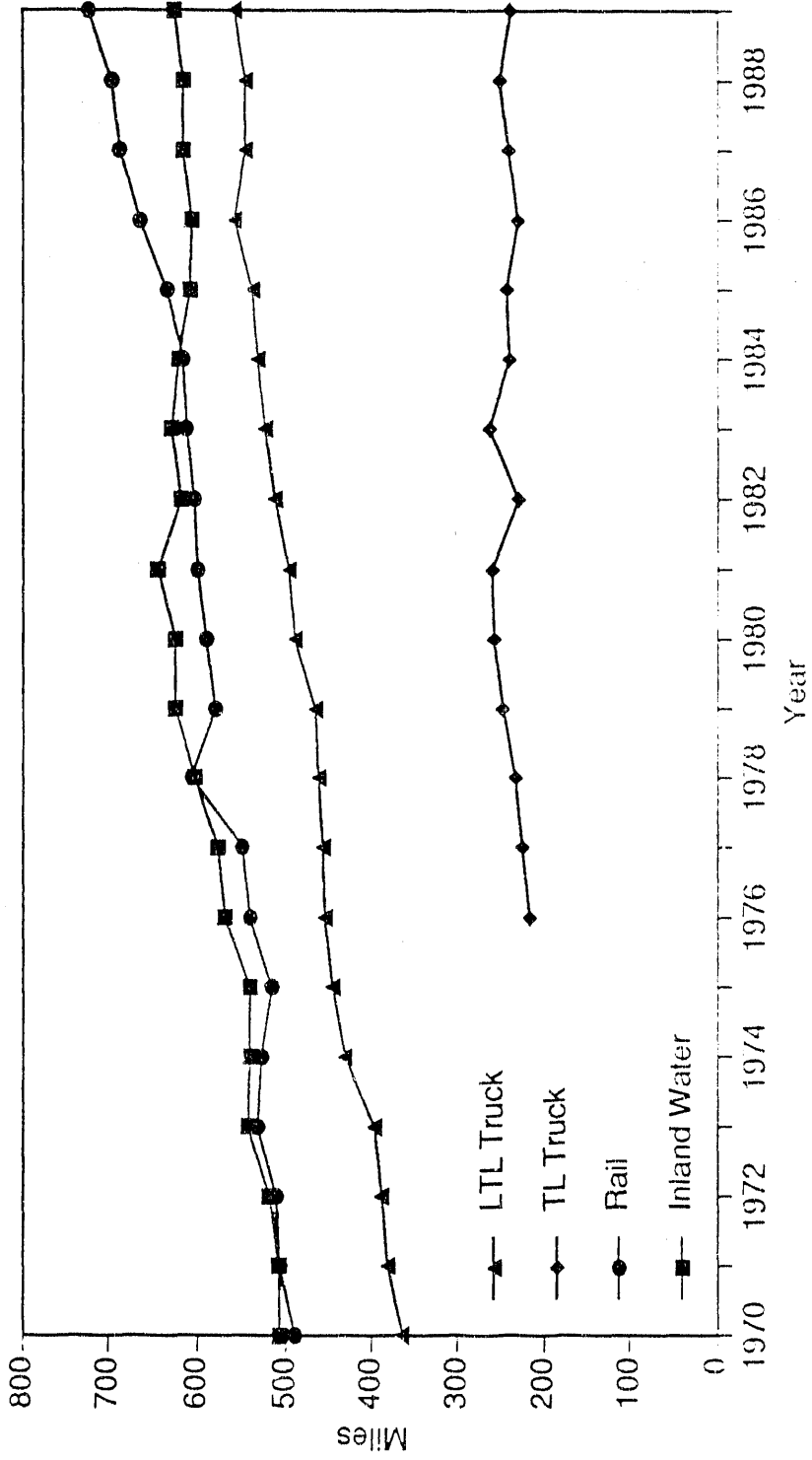


fig. 8

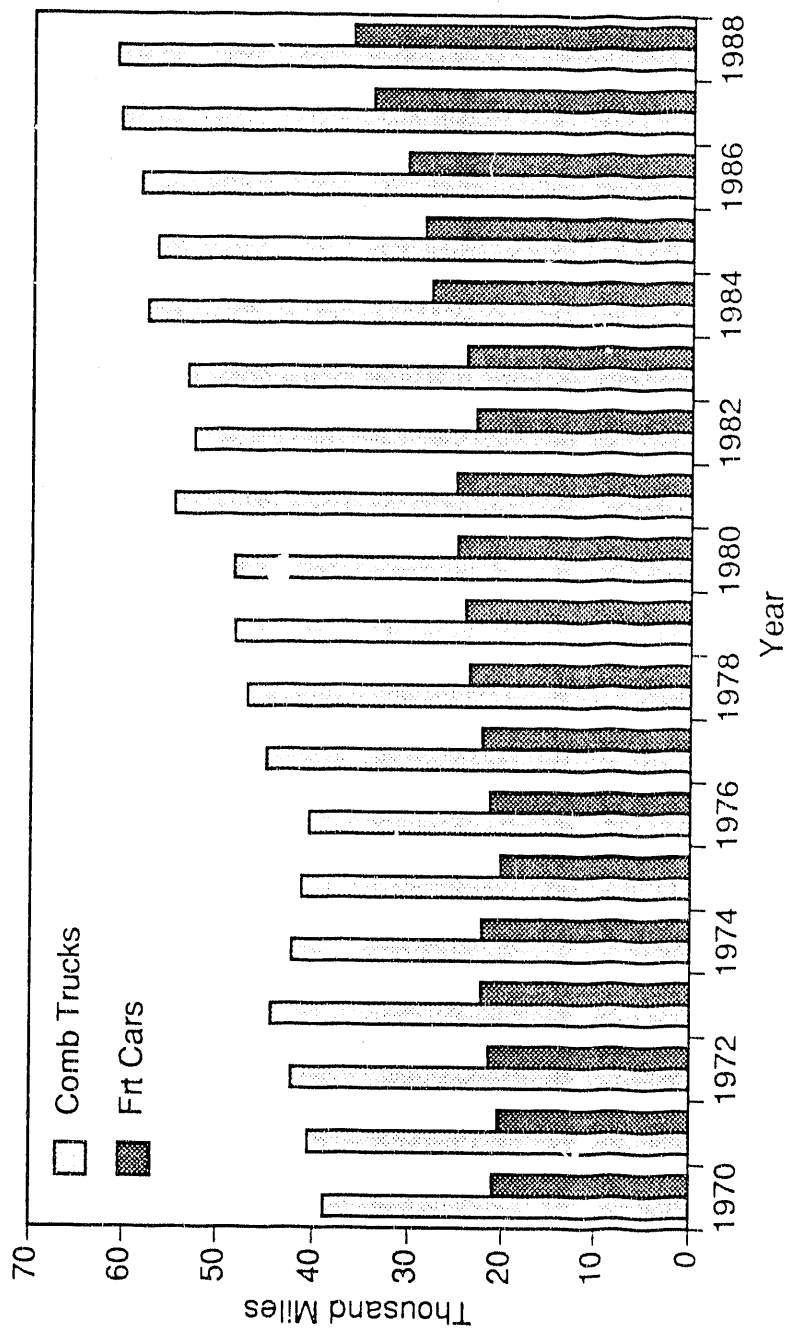
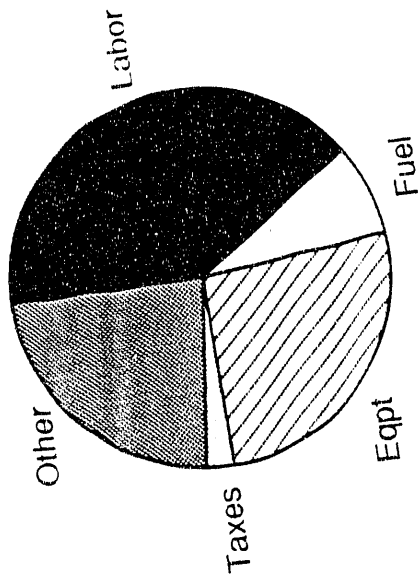
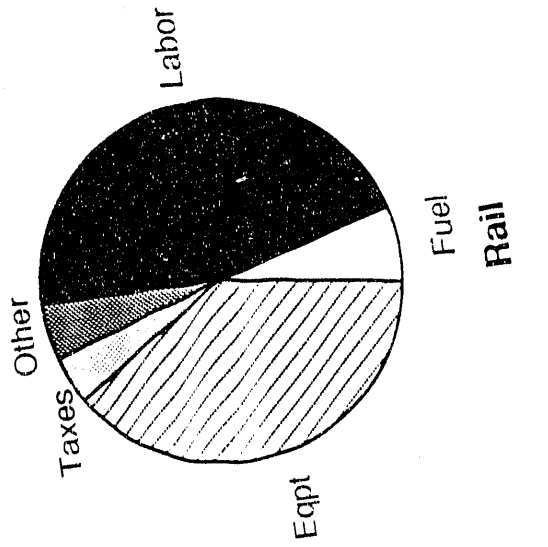
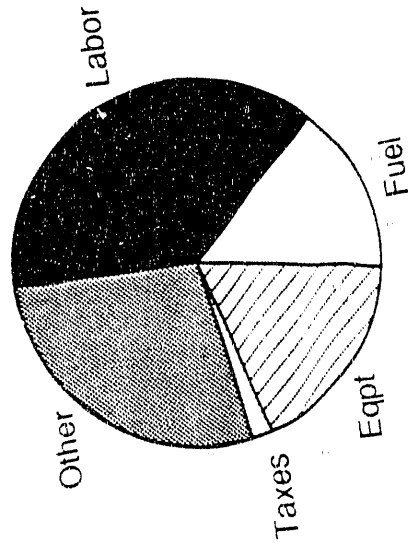


Fig. 9



**Trucks**



**Air**

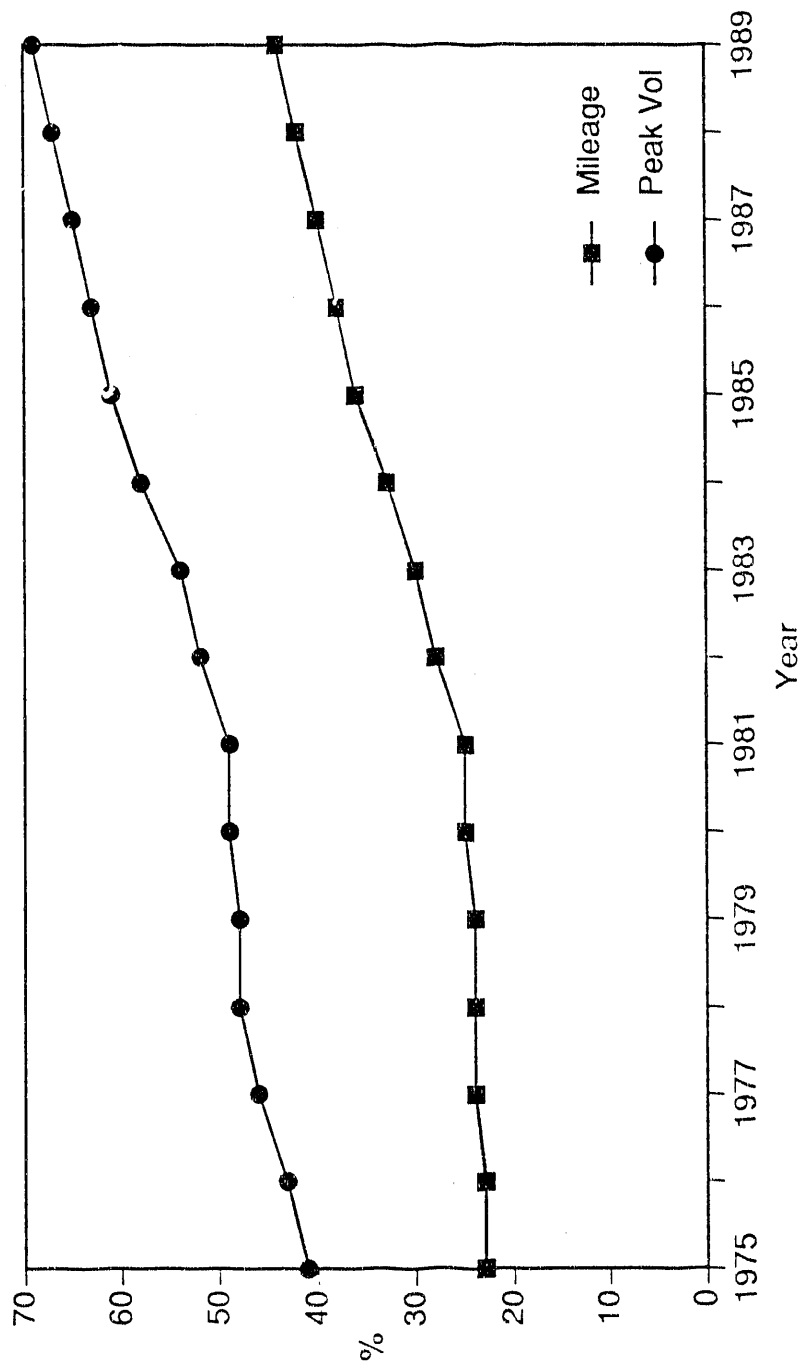
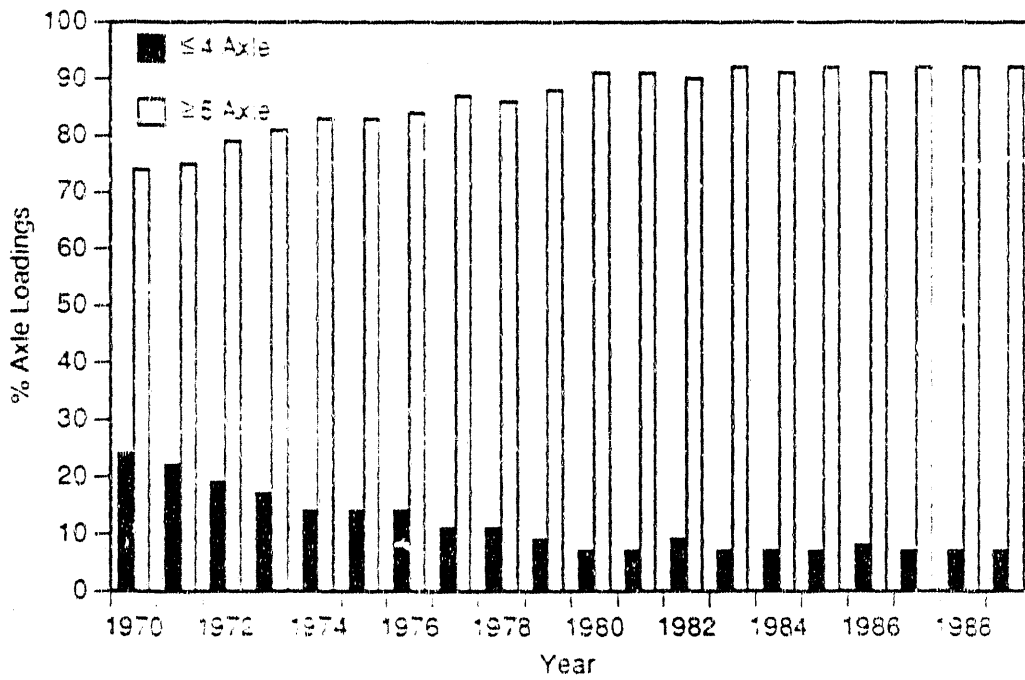
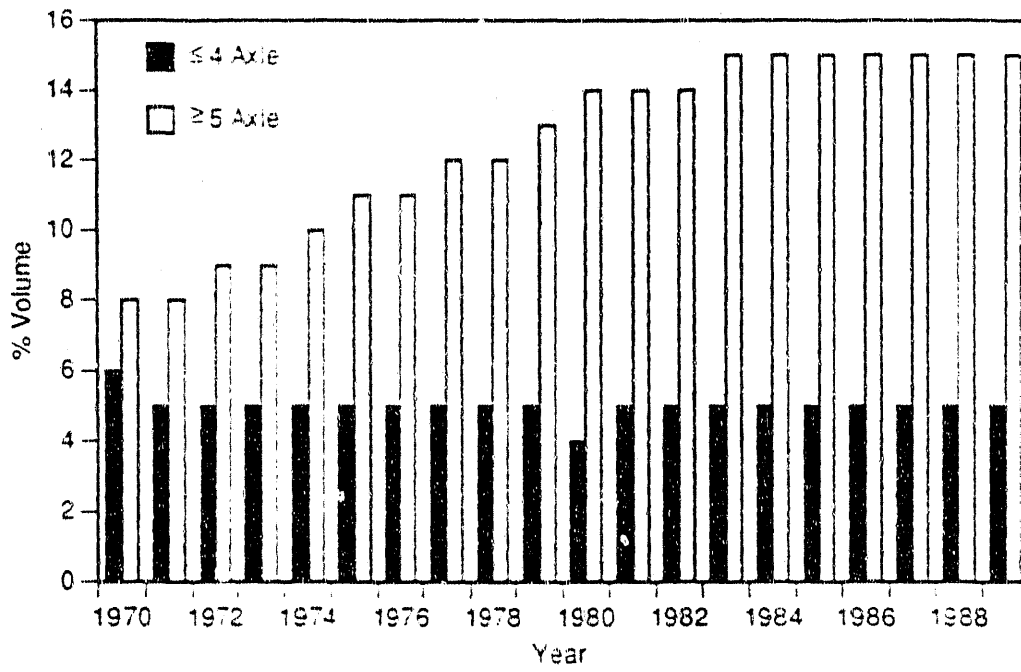


Fig. 11



**END**

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**9 / 08 / 92**

