ANL/ESD/09-3

Analysis of Major Trends in U.S. Commercial Trucking, 1977–2002

Energy Systems Division

About Argonne National Laboratory
Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC under contract DE-AC02-06CH11357. The Laboratory's main facility is outside Chicago, at 9700 South Cass Avenue, Argonne, Illinois 60439. For information about Argonne and its pioneering science and technology programs, see www.anl.gov.

Availability of This Report
This report is available, at no cost, at http://www.osti.gov/bridge. It is also available on paper to the U.S. Department of Energy and its contractors, for a processing fee, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone (865) 576-8401
fax (865) 576-5728
reports@adonis.osti.gov

ANL/ESD/09-3

Analysis of Major Trends in U.S. Commercial Trucking, 1977–2002

---

by
K.M. Bertram, D.J. Santini, J.L. Anderson, and A.D. Vyas
Technology Analysis Section
Center for Transportation Research
Energy Systems Division, Argonne National Laboratory

work sponsored by
The U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy

October 2008

CONTENTS

CONTENTS (Cont.)

FIGURES

TABLES

TABLES (Cont.)

TABLES (Cont.)

Analysis of Major Trends in U.S. Commercial Trucking,1977–2002

by

Kenneth M. Bertram, Danilo J. Santini, John L. Anderson, Anant D. Vyas

ABSTRACT

This report focuses on various major long-range (1977–2002) and intermediate-range (1982–2002) U.S. commercial trucking trends. The primary sources of data for this period were the U.S. Bureau of the Census *Vehicle Inventory and Use Survey* and *Truck Inventory and Use Survey.* In addition, selected 1977–2002 data from the U.S. Department of Energy/Energy Information Administration and from the U.S. Department of Transportation/Federal Highway Administration's *Highway Statistics* were used. The report analyzes (1) overall gasoline and diesel fuel consumption patterns by passenger vehicles and trucks and (2) the population changes and fuels used by all commercial truck classes by selected truck type (single unit or combination), during specified time periods, with cargo-hauling commercial trucks given special emphasis. It also assesses trends in selected vehicle miles traveled, gallons per vehicle miles traveled, and gallons per cargo ton-mile traveled, as well as the effect of cargo tons per truck on fuel consumption. In addition, the report examines long-range trends for related factors (e.g., long-haul mileages driven by heavy trucks) and their impacts on reducing fuel consumption per cargo-ton-mile and the relative shares of total commercial fuel use among truck classes. It identifies the effects of these trends on U.S. petroleum consumption. The report also discusses basic engineering design and performance, national legislation on interstate highway construction, national demographic trends (e.g., suburbanization), and changes in U.S. corporate operations requirements, and it highlights their impacts on both the long-distance hauling and shorter-distance urban and suburban delivery markets of the commercial trucking industry.

SUMMARY

S.1 OVERVIEW

- This report focuses on various major long-range (1977–2002) and intermediate-range (1982–2002) U.S. commercial trucking trends. Primary sources of data for this period were the U.S. Department of Commerce/Bureau of the Census *Vehicle Inventory and Use Survey* and *Truck Inventory and Use Survey* (VIUS/TIUS). In addition, selected 1977–2002 data from the U.S. Department of Energy/Energy Information Administration and the

U.S. Department of Transportation/Federal Highway Administration (FHWA) *Highway Statistics* were used.

- The report addresses the commercial trucking portion of on-road highway vehicles, focusing first on all light-, medium-, and heavy-duty trucks used for commercial purposes, whether they carry cargo or not. These trucks constitute "all commercial trucks." Any tables that compare data from 1977 through 2002 are "all commercial trucks" tables. The report also addresses the subset of commercial trucks used to carry cargo. These trucks are considered "cargo-hauling commercial trucks" (CHCTs). Because of limitations in the questions in the 1977 survey, CHCTs were not identified and focused on in that survey. They were identified in later surveys; thus, any tables that compare data from 1982 through 2002 are CHCT tables.

- Although commercial light-duty vehicles include passenger cars as well as light trucks, only light trucks used for commercial purposes are included in the trucking trends analysis in this report, which relied on TIUS/VIUS data. During the period surveyed, light trucks were used as passenger vehicles more often than they had been before, replacing cars for this purpose. In addition, many passenger cars were used for commercial purposes. The only analysis of passenger cars is in Appendix C, in which their reduced fuel use during 1982–2002 is compared to the fuel use of CHCTs for that period.

- Sections S.2 through S.4 address all commercial trucks from 1977 through 2002, while Sections S.5 through S.7 address CHCTs from 1982 through 2002.

- The report analyzes or discusses analyses of (1) overall gasoline and diesel fuel consumption patterns by passenger vehicles and light-, medium-, and heavy-duty trucks and (2) the population changes and fuels used by single-unit versus combination trucks. It highlights the largest (Class 8) combination trucks (Table S.1), which, in 2002, consumed 68% of all diesel fuel and 42% of all combined diesel and gasoline fuel in all commercial trucking.

- It assesses selected vehicle miles traveled (VMT), gallons per VMT, and gallons per cargo (GPC) ton-mile traveled (TMT) trends, as well as the effect of cargo tons per truck on fuel consumption.

- It also examines long-range trends for related factors (e.g., long-haul mileages traveled by heavy trucks) and their impacts on (1) reducing fuel consumption per cargo TMT, (2) relative shares of total commercial fuel use among truck classes, and (3) U.S. petroleum consumption.

TABLE S.1 Various Truck Categories Used

FHWA Category Used for VMT Data (Truck Type)[a]	Gross Vehicle Weight (GVW) Class[b,c]	GVW or Laden (Loaded) Weight Range (lb)[b,c]
2-axle, 4-tire	1	Less than 6,000
(single-unit)	2	6,001–10,000
2-axle	3	10,001–14,000
6-tire and up	4	14,001–16,000
(single-unit)	5	16,001–19,500
	6	19,501–26,000
	7	26,001–33,000
	8	33,001 and over
Combination	6	19,501–26,000
Trucks	7	26,001–33,000
(Tractor + Trailer)	8	33,001 and over

[a] FHWA, Highway Statistics-Table VM1, Federal Highway Administration, U.S. Department of Transportation.

[b] NHTSA, Vehicle Identification Number Requirements, National Highway Traffic Safety Administration, U.S. Department of Transportation.

[c] VIUS, Vehicle Inventory and Use Survey 1977 through 2002, Bureau of the Census, U.S. Department of Commerce.

- Investigations and discussions were conducted on the effects of basic diesel engine engineering design and performance, national Interstate highway construction legislation, national demographic trends (e.g., suburbanization), and changes in U.S. corporate operational requirements. The report highlights their impacts on both the long-distance hauling and short-distance urban and suburban delivery markets of the commercial trucking industry.

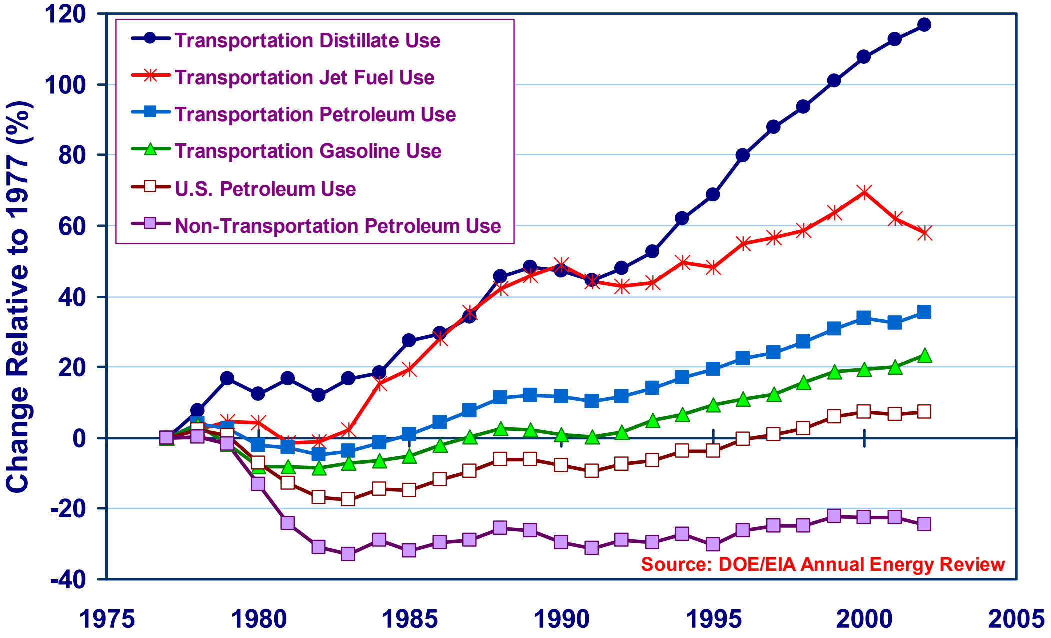
S.2 TRANSPORTATION DISTILLATE USE: FASTEST-GROWING OF ALL THE NATIONAL PETROLEUM END USES, 1977–2002

- Transportation petroleum use grew by 35% in 1977–2002, versus the 7% growth in overall national petroleum use. The annual increase in transportation use of approximately 1.3 billion barrels of petroleum products was significantly higher than the total national petroleum consumption increase of about 0.5 billion barrels (Table 22). In other words, petroleum use outside of transportation declined by 0.8 billion barrels.

- Figure S.1 indicates that overall national use of petroleum for non-transportation applications actually declined in 1977–2002 by about 25%, while its use for transportation applications more than doubled the net national increase. In addition, transportation's share of overall national petroleum use grew from 53% to 67% during this period; it consumed 4.8 of 7.2 billion barrels (Table 22).

- Nationally, the fastest-growing segment of transportation fuel use was distillate (by highway, rail, and marine). Transportation distillate use constituted the fastest-growing element of national petroleum use, as shown in Figure S.1. The use of distillate grew almost as much in absolute terms as did the use of motor gasoline, by about 500 versus 600 million barrels. Because distillate started from a smaller base, it grew at 117% versus 23% for gasoline (Table 22).

- In terms of share of total petroleum use, distillate's share of U.S. petroleum use doubled (from 6.4% to 12.8%), with the fastest rate of share increase (102%) outstripping the corresponding values for gasoline (15%) and transportation (26%). Thus, transportation is both the dominant and fastest-growing national use of petroleum, and within transportation, distillate is the fastest-growing segment (Table 22). Further, within distillate use, trucks increased their share of use (in Btu) from 53% to 71% at the expense of rail and water between 1970 and 2000 (Figure 3), and within trucking fuel use, diesel increased its share from 41% to 62% in the 1977–2002 period, while the share of gasoline decreased from 59% to 38% (Table 23).



Source: DOE/EIA Annual Energy Review

FIGURE S.1 Changes in Petroleum Use, 1977–2002

S.3 CHCTS ON INTERSTATE HIGHWAYS: FASTEST GROWTH IN VMT, 1977–2002

- *VMT increases by type of road system.* In the 1977–2002 period, the VMT of Class 3–8 single-unit and combination CHCTs (Table S.1) had the largest percentage increases on urban and rural Interstates, with combination truck mileages more than tripling (213% increase) and single-unit truck mileages almost tripling (180% increase) on urban Interstates. In 2002, combination trucks recorded 45.7 billion VMT on rural Interstates, an amount that was 61% higher than the VMT of 28.5 billion on the next-highest highway category of "other urban streets" by single-unit trucks. (The FHWA defines "other urban streets" as all roads and streets in urban places with populations of 5,000 or more.) The annual VMT for other urban streets was also high for combination trucks, at 27.2 billion in 2002, an increase of 153% from 1977 (Figure S.2, Table 9).

- *VMT increases by vehicle type.* From 1977 through 2002, on every type of urban and rural road, combination trucks had significantly higher percentage increases in VMT than did Class 3–8 single-unit trucks. Combination truck increases in VMT were 2.6 and 5.2 times those of individual Class 3–8 single-unit truck VMT on urban and rural Interstates, respectively. Individual Class 3–8 single-unit trucks had slightly higher (less than 7%) total VMT than combination trucks only on "other urban streets" and "other rural roads" in 2002, versus the 25% and 68% greater total VMT they had on these roads in 1977 (Figure S.2, Table 9).

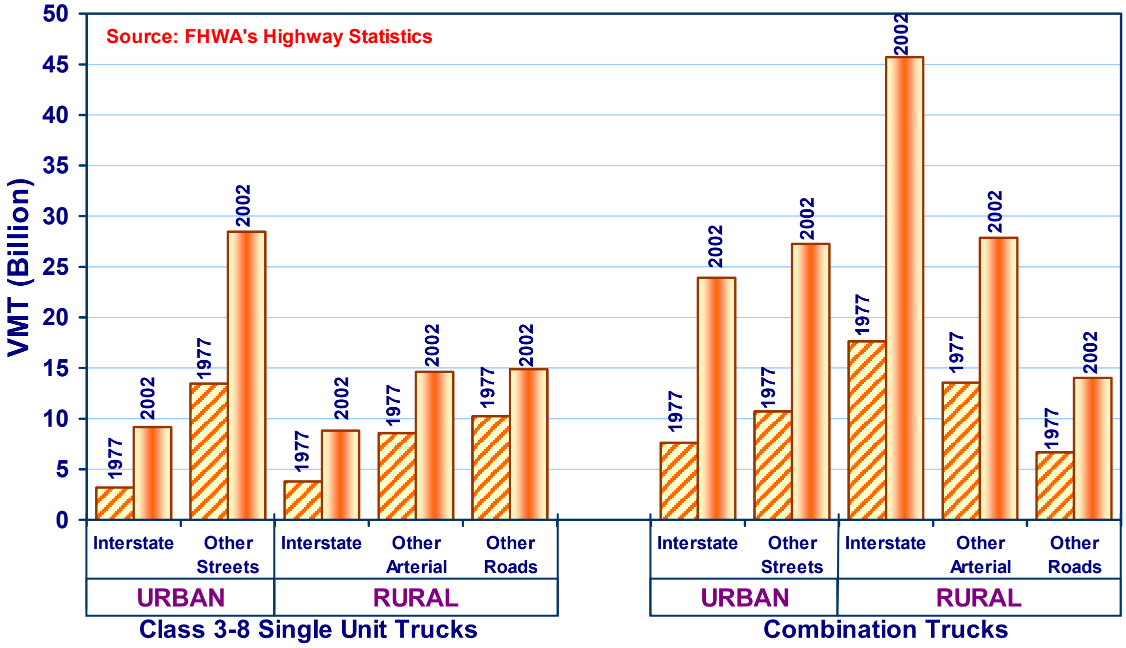


FIGURE S.2 Changes in Total Annual VMT of Single-Unit and Combination Trucks, 1977–2002

S.4 GROWTH OF DIESEL DOMINANCE IN CARGO-HANDLING TRUCKING, CHCT, 1977−2002

- Increases in diesel fuel use:
  - There were very large increases in the percentage and absolute annual volume of diesel fuel use in every commercial truck class in the 1977–2002 period, while gasoline use declined significantly in every class, except light-duty Classes 1 and 2. The total diesel fuel used by the overall truck population in Class 3–8 single-unit trucks increased significantly (Figure S.3, Table 2).
  - The use of gasoline by individual Class 3–8 single-unit trucks declined by 70%. Gasoline lost its once-dominant position in each of these classes to diesel fuel, the use of which increased by 368%. The dominance of diesel was already in place in combination trucks in 1977, when 98% of this diesel fuel was consumed by Class 8 trucks. Diesel use increased to 99% of combination truck fuel use by 2002 (Figure S.3, Table 2).
  - Between 1977 and 2002, the use of diesel fuel by Class 8 combination trucks almost doubled from 8.1 to 15.2 billion gallons (87% increase). For Class 8 single-unit trucks, the increased use of diesel fuel was even greater in percentage terms (167%). For gasoline use, the declines in Class 8 were dramatic in percentage terms, at 87% for single-unit trucks and 96% for combination trucks (Figure S.3, Table 2).

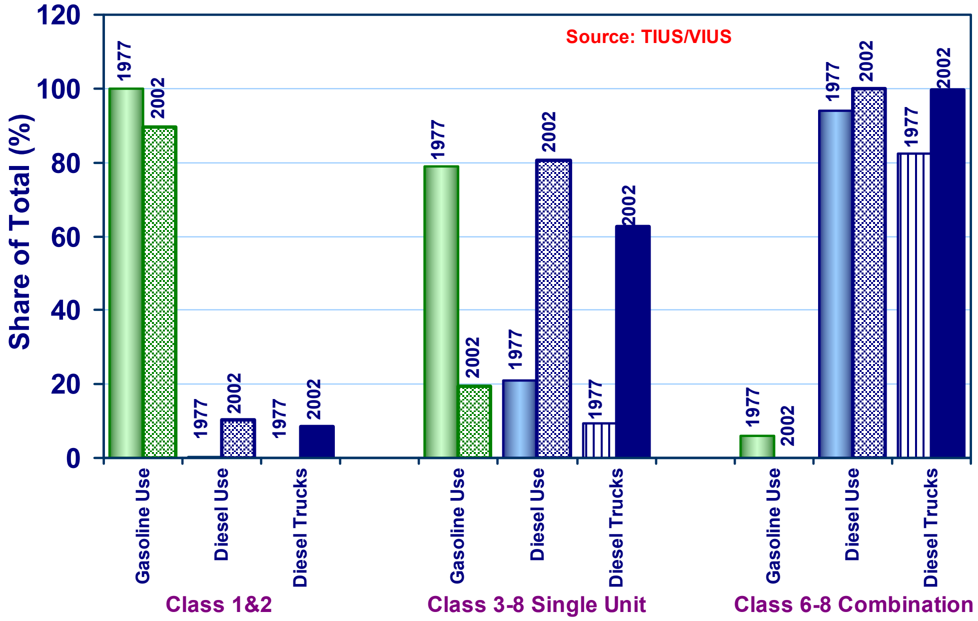


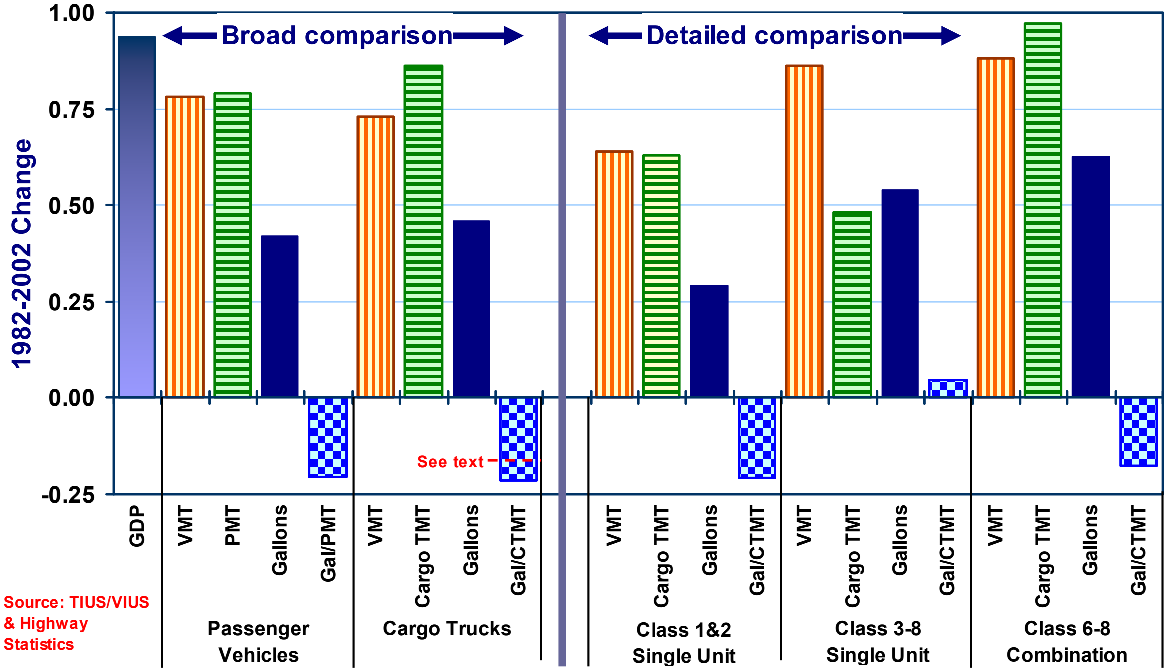
FIGURE S.3 Commercial Truck Gasoline and Diesel Fuel Use and Diesel Truck Populations, 1977–2002

- Increases in diesel truck population:
  - The populations of Class 1–2 and Class 3–8 single-unit and Class 6–8 combination diesel trucks increased during the period, with Class 1–2 trucks having the largest percentage increases and Class 3–8 single-unit trucks having the largest total population increase. The change in percentage share versus gasoline trucks was greatest for Class 3–8 single-unit trucks.
  - Class 1–2 diesel trucks increased their share from near 0% in 1977 to 8% in 2002, with an increase in population of about 12,600%, from about 8,400 trucks to 1.07 million trucks (Figure S.3, Table 3).
  - Class 3–8 single-unit diesel trucks increased their share from 9% in 1977 to 62% in 2002, with an increase in truck population from 262,000 to 2.03 million, or 677% (Figure S.3, Table 4).
  - Diesel trucks increased their share within Class 6–8 combination trucks from 82% in 1977 to 99% in 2002 (Figure S-3). Class 8 combination trucks composed 98% of combination diesel trucks, the number of which increased from 671,000 to 1.35 million, or 101%, from 1977 through 2002, as shown in Table 4.

S.5 REDUCTION IN FUEL CONSUMPTION BY CHCTS VERSUS PASSENGER VEHICLES, 1982−2002

S.5.1 Broad Comparison of CHCT Versus Passenger Vehicle Fuel Use Effectiveness

- CHCT fuel use effectiveness was calculated in terms of *fuel used per cargo ton-mile traveled* (TMT). Results indicated a reduction of about 21% over the period 1982–2002 (Figure S.4, Table 16). This estimate was compared to a logically comparable measure for passenger vehicles: *fuel used per passenger mile of travel*. On the basis of FHWA estimates for highway passenger vehicles, there was also a reduction of about 21% in passenger fleet fuel consumed per passenger mile in 1982–2002 (Figure S.4, Table C-1).
- During 1982–2002, cargo trucks and passenger vehicles also had similar percentage increases in their VMT, cargo TMT and passenger miles, and combined total gallons of gasoline and diesel fuel consumed.



Source: TIUS/VIUS & Highway Statistics

FIGURE S.4 Changes in Fuel Use Effectiveness of CHCTs versus Passenger Vehicles, Overall and by Truck Class Group, 1977–2002

- The shift of CHCTs away from gasoline and toward diesel (distillate) fuel that caused the 98–137% increase in consumption of highway distillate fuel exceeded the 94% rate of growth of real gross domestic product (GDP) over the 1982–2002 period.

- However, because of declining gasoline use, total growth in fuel gallons used by CHCTs (gasoline and distillate) was estimated to increase by only 46%, while the total TMT increase was 86% for all CHCT classes. Both were well below the GDP growth. Thus, CHCTs contributed significantly to the reduction in the energy intensity of the economy over this period.

S.5.2 Detailed Comparison of Cargo Truck Class Groups

- Estimated changes in fuel consumption per cargo TMT for the three truck categories were –20.9% for Class 1–2 CHCTs (2-axle, 4-tire trucks), +4.5% for individual Class 3–8 single-unit trucks (2-axle, 6-tire or more trucks), and –17.5% for Class 6–8 combination trucks. Because of the positive mix effects (an increasing share of cargo TMT handled by Class 8 combination trucks), the estimate for all of these CHCTs combined was –21.4%, as previously noted (Figure S.4, Table 16).

- Isolating the trucks being used to haul cargo led to estimates that the rate of growth in the number of trucks dedicated to cargo hauling increased steadily as the trucks went from the lighter to heavier categories: from 31% to 49% to 57%, respectively (Table 16).

- Similarly, 2002 shares of total cargo TMT increased significantly from the lighter to heavier vehicle categories: from 156 billion to 298 billion to 1.82 trillion TMT, or from 7% to 13% to 80%, respectively (Table 16).

- Furthermore, these 2002 percentages were the result of overall TMT share decreases (from 1982 levels): from 8% to 7% for Class 1–2 trucks and from 17% to 13% for Class 3–8 single-unit trucks. They resulted in a share increase of 4%, from 76% to 80%, for combination trucks. Because the estimated efficiency in hauling cargo increased considerably as trucks went from lighter to heavier categories, the net fleet system efficiency rose accordingly (Table 16).

- *Truck mix shift effects — toward heavier, more efficient trucks — caused the aggregate systemwide percentage reduction (–21.4%) in GPCTMT to exceed the percentage amount for each single class.*

S.6 CHANGES IN CARGO TONS PER TRUCK, 1982−2002

- From 1982 to 2002, the Class 8 combination diesel truck class was the only diesel or gasoline truck class to have a net increase in cargo tons per truck (Figure S.5) (from 19.9 to 20.6 tons). This, combined with the largest VMT increases, almost doubled the cargo TMT increase (see Detailed Comparison graph in Figure S.4 and Tables 16 and 17). Most other truck classes had double-digit percentage *decreases* in cargo tons per truck, and virtually all other truck classes had double-digit cargo TMT per truck decreases (Table 10).

- *In the same period, the Class 8 combination trucks also had the best improvement in GPCTMT of 15%; the 1982 all-classes best GPCTMT of 0.0097 was reduced to 0.0082 in 2002 (see Detailed Comparison graph in Figure S.4). The next-best 2002 GPCTMT was 0.0119 for individual Class 8 single-unit trucks, which was a very significant 45% higher (Table 13).*

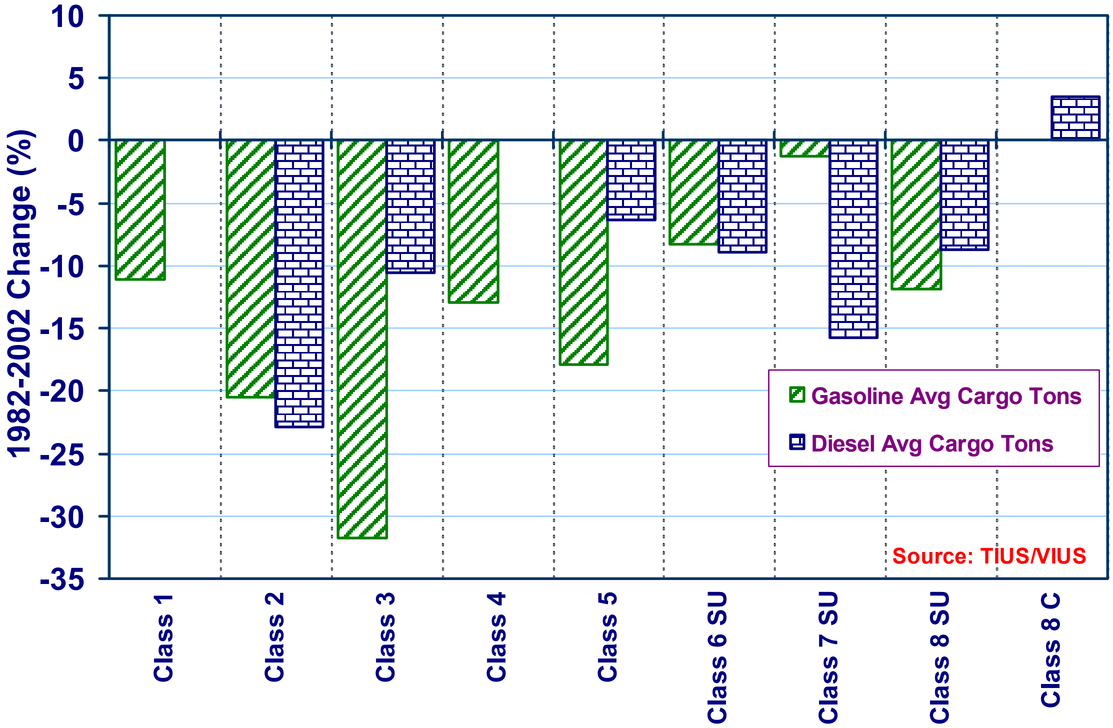


FIGURE S.5 Percent Change in Cargo Weights by Truck Class and Fuel Type, 1982–2002

S.7 COMPARISON OF CLASS 8 COMBINATION DIESEL CHCTS VERSUS CLASS 3−8 SINGLE-UNIT DIESEL CHCTS BY USUAL OPERATING AREA, 1982−2002

- From 1982 to 2002, Class 8 combination (8C) diesel trucks that usually operated for >50 miles had a 12.5% increase in annual VMT per truck, or an increase of about 9,000 miles (from 72,773 to 81,860 miles), whereas for trucks that operated ≤50 miles, the annual VMT per truck decreased by about 3,000 VMT from 31,212 to 28,556 miles (–8.5%).

- Also, Class 8C trucks that usually operated >50 miles increased their share of overall Class 8C VMT from 85.9% to 87.2% (+1.6%); the share of those operating ≤50 miles dropped from 14.1% to 12.8% (–9.2%). The increases in VMT per truck and VMT shares of the long-haul trucks, in combination with the increased tons, resulted in the 15.8% or 235,000-mile increase in annual cargo TMT per truck for Class 8 combination diesel trucks operating >50 miles versus the 6% or 38,000-mile decrease in annual cargo TMT per truck for Class 8C trucks operating ≤50 miles (Figure S.6, Table 18).

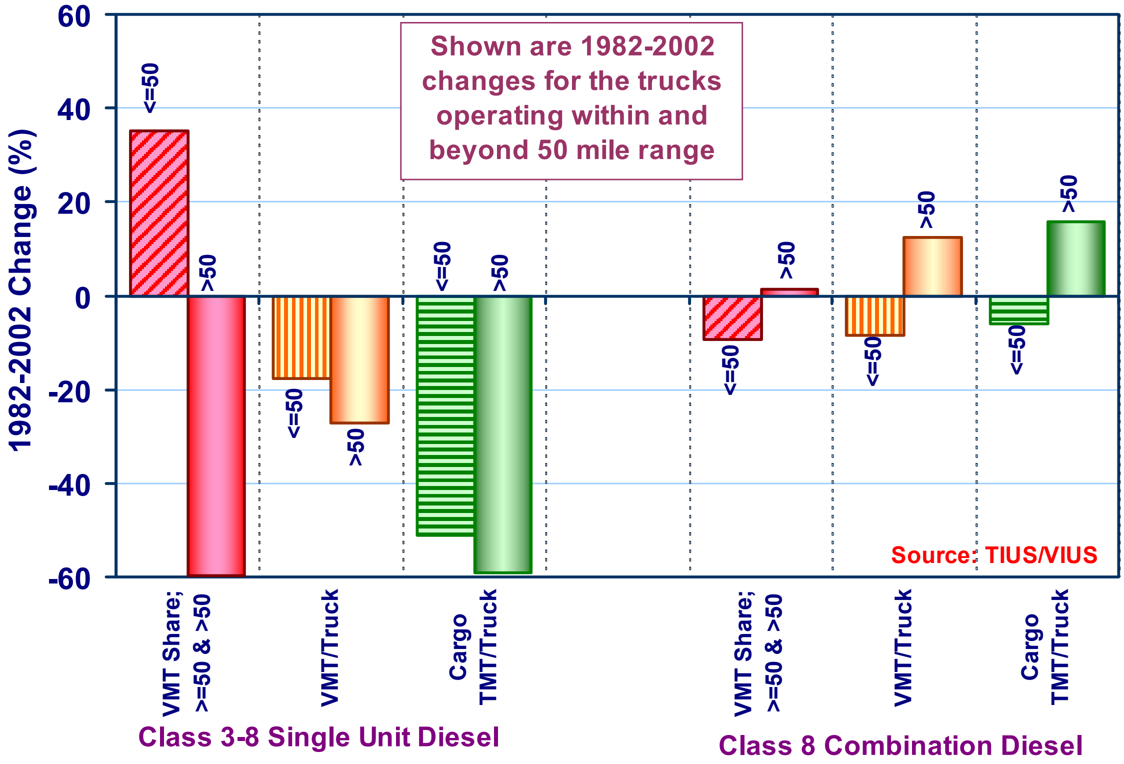
- Most of the cargo shifted from individual single-unit Class 3–8 trucks into Class 8C trucks traveling >50 miles, because Class 8C trucks operating

≤50 miles did not gain but instead lost 5.5% of their annual cargo TMT share (Figure S.6, Table 18).

- Dramatic decreases of 51% and 59% in the weighted average cargo TMT for individual Class 3–8 single-unit diesel trucks were experienced for trips of ≤50 miles and >50 miles, respectively. Also, individual Class 3–8 single-unit diesel trucks traveling ≤50 miles increased their share of annual VMT by 35%, at the expense of longer (>50-mile) trips by these trucks, the share of which decreased by 60% (Figure S.6, Table 18).

S.8 SUMMARY AND CONCLUSIONS

- Because highway diesel fuel had the fastest growth rate (135%, Table 23) of all national petroleum fuels, and because the dominant user of distillate was truck transport, the major reduction in gasoline use (Figure S.3, Table 2) and GPCTMT (–21%, Table 16)[1] by the CHCT fleet between 1982 and 2002 is



Source: TIUS/VIUS

FIGURE S.6 Changes in VMT and Cargo per Truck for Single-Unit and Combination Trucks by Usual Trip Length, 1982–2002

---

[1] FHWA data discussed and presented in Appendix C and Table C-1 indicate that this estimated 21% reduction in fuel consumption by CHCTs is comparable to the estimated 21% reduction in fuel consumption (for passenger miles traveled) by the passenger vehicle fleet.

important. This reduction has resulted in far more efficient use of the 68% of highway diesel fuel consumed by Class 8 combination trucks in 2002 (Table 2), as transportation use of petroleum grew from 53% to 67% in the 1977–2002 period (Table 22).

- Most of the GPCTMT reduction came from cargo shifts from single-unit gasoline and diesel Class 3–8 trucks to the most efficient Class 8 combination diesel trucks traveling >50 miles (Figure S.4, Tables 10, 15, 17, and 18). These trucks had by far the best fuel efficiency of 0.0082 GPCTMT, which improved by 16% in the 1982–2002 period, and which was 45% better than the next-lowest GPCTMT of 0.0119 for Class 8 single-unit diesel trucks (Table 15).

- Five probable factors contributed to these trends:

  1. Basic engineering design and performance (especially durability) advantages of diesel engines over gasoline engines played a major role in the huge shift of Class 3–8 gasoline-powered single-unit trucks in 1977 to diesel trucks in those classes; they then became totally dominant in 2002 (Tables 4 and 5).

  2. The 42,000-mile interstate highway system, constructed specifically to foster long-distance, steady-speed trips, was conducive to Class 8C diesel truck fuel efficiency.

  3. Demographic population shifts from densely populated central cities to dispersed suburbs, plus increased international trade through the nation's coastal seaports, required more long-distance cargo trips.

  4. Truck transportation operating requirements changed to address serving metropolitan areas with increasingly large and dispersed suburbs at the expense of central cities. The needs of these areas were best met by durable diesel engine CHCTs in the new operating environments. The greater distances being driven annually in 2002 versus 1977 by both single-unit and combination trucks are shown in Table 9 by roadway category and overall.

  5. A 1982 federal law (*United States Code,* Title 23, "Highways, Federal Truck Size and Weight Laws," Section 127, "Vehicle Weight and Size Limitations — Interstate System,") gave the trucking industry permission to operate heavier trucks on the nation's Interstates, albeit with sharply higher use and excise taxes. This law facilitated unobstructed growth of the largest Class 8C diesel trucks in interstate commerce and enabled these long-distance heavy trucks to take advantage of their inherent fuel-efficiency advantages. It could be called the "final piece in the puzzle," since it literally and legally allowed these truckers to take advantage of

other factors (e.g., basic diesel engine engineering design and performance, infrastructure improvements, and resultant operational requirements) that led to increased use of diesel fuel in all truck classes.

- However, a reduction in cargo weight per truck in individual Class 3–8 single-unit diesel trucks diminished the contribution of these trucks to the overall CHCT fleet reductions in GPCTMT achieved primarily by Class 8 combination diesel trucks (Tables 13, 15, and 16). The heavier engines of all diesel trucks also reduced their cargo-hauling fuel savings. That factor led to the conclusion that the durability of the diesel engine was a more important reason for its adoption in Class 3–8 single-unit trucks than was improved technical efficiency. (Technical efficiency considers the fuel used per total vehicle mass under standard operating conditions rather than fuel used per unit of cargo carried under changing "in-use" operating conditions.)

- The expected continuing dominance of diesel CHCTs (especially Class 8C diesels) in the trucking industry — and the obvious favorable impact of these trucks on reducing transportation fuel consumption — provide strong justification for national energy and environmental policies that support federal research on ways of further improving the fuel efficiency and durability of diesel truck engines while reducing their environmental impacts. One question raised by our research is whether the apparent long-run benefits of the system-efficiency–enhancing legislation of 1982 have been largely exhausted. Does the interstate highway infrastructure require another adequately funded upgrade, and should the size and weight limits of trucks again be raised?

S.9 FINDINGS, OBSERVATIONS, AND RECOMMENDATIONS FOR FURTHER RESEARCH

- *Primary finding.* The shift to the Class 8 combination diesel truck for hauling cargo, enabled by an improved and upgraded interstate highway system, enhanced the overall cargo-hauling system efficiency of the highway network by enabling shifts to (1) a higher share of cargo carriage by the more efficient diesel powertrain and (2) inherently more cargo-efficient large trucks.

  Research recommendations. Investigate two issues: (1) For cargo-hauling purposes, does the interstate highway system need another adequately funded upgrade that will enable the use of still larger combination trucks? (2) Should the size and weight limits of trucks be raised beyond the increases legislated in 1982 that facilitated the shift of cargo to fuel-efficient Class 8 diesel trucks?

- *Finding.* Although it was found that Class 8 diesel combination trucks had both huge fuel efficiency and durability advantages over gasoline trucks, among smaller Class 3–8 single-unit trucks, the durability of the diesel engine was a more important reason for its adoption than its fuel efficiency advantage. Although the durability of Class 3–8 truck diesel engines was and is likely to continue to be formidable, the fuel efficiency advantage decreased over the study period, because the trucks suffered from greater losses in cargo weights carried as a result of a combination of (1) higher diesel powertrain weights for single-unit trucks typically used on roads and highways with specific weight limits, which thus reduced allowable cargo capacities per truck, and (2) just-in-time logistic operational strategies moving loads on demand rather than when fully loaded.

Research recommendation. Examine the logistics trade-offs between just-in-time and when-fully-loaded operational strategies for single-unit trucks used in urban delivery. Consider fuel saved via use of full loads versus the necessary warehousing for customers to cope with more intermittent delivery.

- *Observation.* Since 2002, regulations imposed to reduce emissions of particulates and nitrogen oxides from diesel engines have eliminated the diesel engine's advantage over gasoline engines (which have less strict emission regulations). Costly, sophisticated after-treatment equipment is required on diesel powertrains, as is much more "severe" refining of increasingly costly diesel fuels to remove sulfur. Therefore, the gasoline truck engine — perhaps with the help of hybridization and regenerative braking — may be able to slow the rate of expansion of the diesel powertrain, particularly in the case of Class 3–8 single-unit gasoline trucks, which are often light-cargo urban-delivery and service-call vehicles and usually travel ≤50 miles on roads that require frequent stops. Such trips greatly increase the competitiveness of hybridization. Similarly, because these single-unit trucks tend to have a higher percentage of vehicle load on driven axles than do combination trucks and trailer sets, a positive energy-saving feature is created for hybrid powertrains. However, diesel powertrains can also be hybridized. Nevertheless, the durability advantage of diesel engines is likely to persist, albeit with a narrowing of that advantage.

  Research recommendation. National energy and environmental policies should support federal research on ways of improving the fuel efficiency and durability of commercial diesel and gasoline truck powertrains (e.g., examine the fuel saving vs. durability implications of hybridizing them) while reducing their environmental impacts.

- *Observation.* During this research, the available data were inadequate for delineating the behavior of commercial vehicles whose primary purpose was not cargo hauling. The TIUS and VIUS ignored passenger cars altogether. Thus, commercial uses of passenger cars could not be studied. Also, the fuel consumption data for trucks not carrying cargo were of very poor quality. The 1982–2002 research on CHCT trends, while resulting in much useful information and several valuable conclusions and findings, neglects the fuel consumption of non-cargo-hauling commercial vehicles.

Research recommendations. Research should be done on the behavior and fuel consumption of non-cargo-hauling commercial vehicles, including the commercial use of passenger cars. To understand non-cargo-hauling commercial vehicles, a completely new survey structure, which accurately delineates their operating characteristics (e.g., trip lengths) and fuel consumption behavior, is needed. Such data will help define the size and nature of the potential market for new technologies (such as hybrid powertrains using regenerative braking), which are at their greatest relative competitiveness for these non-cargo-hauling commercial vehicles that we believe are disproportionately used for urban deliveries and service calls. Public policy to promote fuel efficiency will be fundamentally different for these commercial vehicles than for personal-use vehicles. Accordingly, the nature of the commercial non-cargo-hauling vehicle market needs to be well defined if good oil-saving research and development strategies and public policies are to be implemented for this segment of the on-highway market.

This page intentionally left blank.

1 INTRODUCTION

This report focuses on major long-range (1977–2002) and intermediate-range (1987–2002) U.S. commercial trucking trends. The primary sources of data for this period were the results of the U.S. Department of Commerce (DOC)/Bureau of the Census *Vehicle Inventory and Use Survey* and *Truck Inventory and Use Survey* (VIUS/TIUS)[2] for the years selected for analysis. In addition, selected data from the U.S. Department of Energy/Energy Information Administration (DOE/EIA) and from the U.S. Department of Transportation Federal Highway Administration (DOT/FHWA) *Highway Statistics* were used.

This report analyzes (1) overall gasoline and diesel fuel consumption patterns for passenger vehicles (cars and light trucks) versus commercial light, medium, and heavy trucks; (2) the population changes and fuels used by all commercial truck classes by selected truck type (single-unit [straight] or combination; sometimes abbreviated SU or C); and (3) the subset of commercial trucks that normally carry cargo: cargo-hauling commercial trucks (CHCTs). The analysis of all commercial trucks compares data from 1977 through 2002. Because of limitations in survey questions, analyses of CHCTs compare data from 1982 through 2002. Trends in selected vehicle miles traveled (VMT), VMT per gallon, and ton-miles traveled (TMT) per gallon, as well as the effect of cargo tons per truck on fuel consumption, are also assessed.

In addition, this report examines long-range trends of related factors, such as long-haul mileages driven by heavy-freight vehicles and their impacts on relative shares of total commercial fuel use among truck classes. The impacts of these trends on U.S. petroleum consumption are identified, as are the impacts of national interstate highway (Interstate) construction legislation, national demographic trends (e.g., suburbanization), and U.S. corporate operational policies (e.g., just-in-time delivery and “big box retailing”). Their impacts on both the long-distance hauling and shorter-distance urban and suburban delivery markets of the commercial trucking industry are highlighted.

---

[2] U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006, *Truck Inventory and Use Survey* and *Vehicle Inventory and Use Survey* summaries and micro-data files. These sources are used throughout this report and are hereafter referred to in an abbreviated form as “TIUS/VIUS data.”

This page intentionally left blank.

2 TRUCK CONFIGURATION AND CLASS DEFINITIONS

Truck configurations and classes are defined here, at the outset of this report, because of their pervasive use in the data comparisons that follow. The two truck configurations used in this report are single-unit (SU) trucks, which consist of engine, driver, and inseparable cargo compartments, and combination (C) trucks, in which cargo vans, platforms, tanks, or bin-type units are separable from the tractors that house the engine and driver. Truck classes, according to a truck manufacturers industry definition used by the U.S. Bureau of the Census, are determined by gross vehicle weight or GVW (truck vehicle weight plus cargo weight), as shown in Table 1.

According to the 2002 VIUS, among the trucks that are in use, the vast majority of combination trucks are Class 8 trucks (97.4%), with the remaining 2.6% being either Class 6 (0.8%) or Class 7 (1.8%). There are single-unit trucks in all truck classes, and, for record-keeping purposes, the FHWA in its annual *Highway Statistics* publication separates them into two categories: those with two axles and four tires and those with two or more axles and six or more tires. Medium- and heavy-duty single-unit trucks are on at least two axles (but often more when they are designed to carry heavier cargo) and have six or more tires. Light-duty vans, pickup trucks, and sport/utility vehicles have only two axles and four tires.

TABLE 1 Vehicle Manufacturer Truck Classification

Category[a]	Class[b,c]	Gross Vehicle Weight (lb)[b,c]
Light	1	Less than 6,000
	2A[d]	6,001–8,500
	2B[d]	8,501–10,000
Medium	3	10,001–14,000
	4	14,001–16,000
	5	16,001–19,500
	6	19,501–26,000
Heavy	7	26,001–33,000
	8	33,001 and over

[a] *Annual Energy Outlook 2005, Table 33*, Energy Information Administration, U.S. Department of Energy.

[b] *Vehicle Identification Number Requirements*, National Highway Traffic Safety Administration, U.S. Department of Transportation.

[c] *Vehicle Use and Inventory Survey 1977 through 2002*, Bureau of the Census, U.S. Department of Commerce.

[d] Light truck classified for fuel economy standards prior to MY 2011 and emissions regulations purposes, 43CFR11995, 11997, March 1978.

This page intentionally left blank.

3 BACKGROUND

In 1983, a matrix of truck energy-efficiency measures was published in a study funded by DOE's Office of Vehicle and Engine Research and Development (Bertram et al. 1983). It recommended the use of high-torque, low-rpm (revolutions per minute) diesel engines that are turbocharged and aftercooled in all new trucks. The most recent TIUS data available at the time indicated that in 1977, diesel trucks represented about 11% of Class 3–7 trucks (10,000–33,000 lb GVW, most of which were single-unit trucks), 65% of Class 8 trucks (>33,000 lb GVW single-unit trucks), and about 95% of Class 8 combination trucks (tractor-trailers >33,000 lb GVW). In 1984, shortly after the matrix was published, TIUS 1982 data became available. They indicated that a strong increase in the market share of diesel trucks versus gasoline-powered trucks was already under way; for example, the Class 3–7 share had increased from 11% to 20%. That trend continued for another 20 years, contributing to a steady improvement in truck energy efficiency, with significant implications in the commercial trucking industry with regard to the types of fuels and trucks used.

Described in the following pages is how diesel dominance grew in the 1977–2002 period, as evidenced in the numbers of medium and heavy single-unit trucks and the increased use of diesel fuel by these and Class 8 combination trucks, and how this diesel dominance affected the overall freight-carrying efficiency and rates of fuel consumption of the truck classes. Past and potential growth in the market share of light-duty (<10,000 lb GVW) diesel trucks is also examined.

This page intentionally left blank.

4 GROWING DIESEL DOMINANCE IN ALL COMMERCIAL TRUCKING, 1977–2002

4.1 INCREASES IN DIESEL FUEL USE

As indicated in Table 2, there were significant increases in diesel fuel use (in terms of both percentages and absolute annual volumes measured in gallons) in every commercial truck class for the 1977–2002 period, with an overall total increase of 135%. Gasoline use, however, declined in every class except light-duty Classes 1 and 2. As a result of the decline in gasoline use, the total fuel used by the overall truck population in Classes 3–8 increased by only 23%. Table 2 shows how gasoline use declined significantly in all medium-duty Class 3–6 trucks (see Table 1) and heavy-duty Class 7 trucks and, as a result, lost its once dominant position in each of these classes to diesel fuel. The dominance of diesel was already in place in Class 8 trucks in 1977. This diesel dominance by Class 8 combination trucks increased even more from 1977

TABLE 2 Use and Share of Gasoline and Diesel Fuel by All Commercial Trucks, 1977–2002

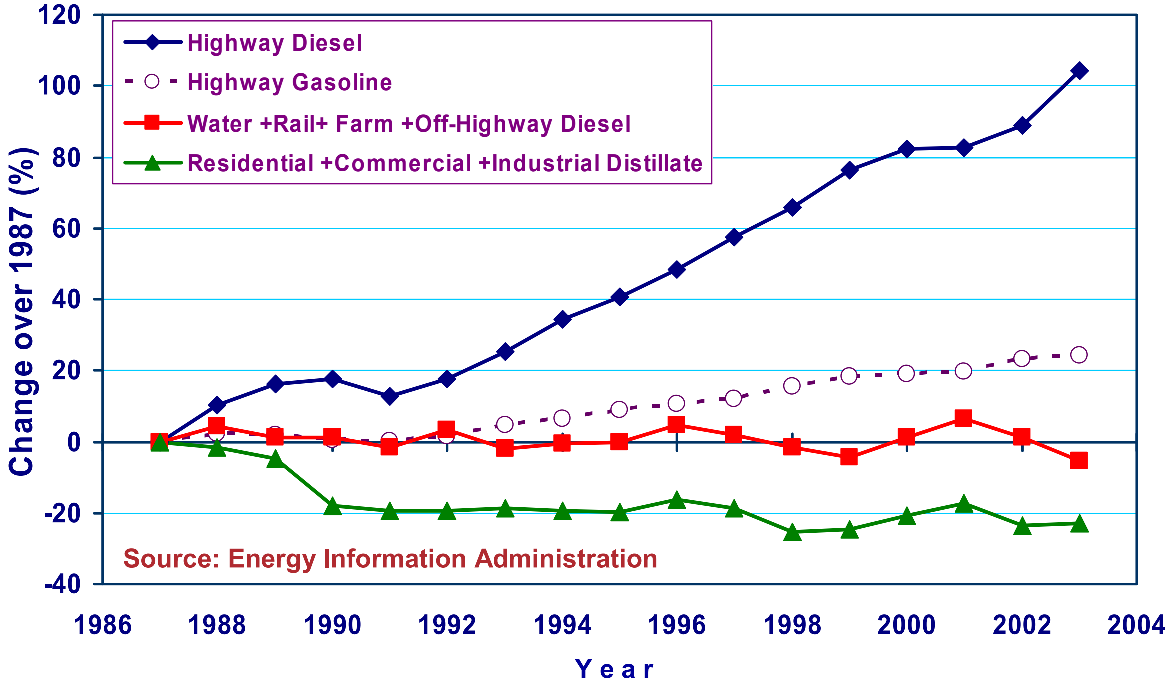
	Estimated Gasoline Use (10^6 gal)			Estimated Diesel Use (10^6 gal) and Share				
Truck GVW Class and Type	1977	2002	% Change in Gasoline Use, 1977–2002	1977	Share of Total (%)	2002	Share of Total (%)	% Change in Diesel Use, 1977–2002
1SU	5,774	7,237	25	5	0.1	282	1.3	5,206
2SU	3,089	5,163	67	9	0.1	1,135	5.1	12,953
Light-duty total	8,863	12,400	40	14	0.1	1,416	6.3	10,016
3SU	922	586	−36	17	0.2	627	2.8	3,585
4SU	424	161	−62	19	0.2	404	1.8	2,062
5SU	777	135	−83	25	0.3	386	1.7	1,458
6SU	1,233	301	−76	121	1.3	1,162	5.2	861
7SU	554	93	−83	127	1.3	601	2.7	371
8SU	474	62	−87	867	9.1	2,316	10.4	167
Class 3–8SU total	4,384	1,337	−70	1,175	12.5	5,496	24.6	368
Class 1–8SU total	13,248	13,736	4	1,189	12.5	6,912	31.0	481
6C	54	2	−97	55	0.6	58	0.3	5
7C	65	1	−99	142	1.5	130	0.6	−9
8C	411	16	−96	8,123	85.4	15,229	68.2	87
Combination total	529	18	−97	8,320	87.5	15,416	69.0	85
Total	13,777	13,755	0	9,510	100	22,328	100	135

Source: DOC; U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

through 2002 as a result of the near doubling of diesel use (increase of 87%, from 8.12 to 15.23 billion gallons), while gasoline use in Class 8 combination trucks fell by 96%, from 411 to 16 million gallons. Similarly, fuel use by Class 8 single-unit diesel trucks increased from 867 million to 2.32 billion gallons (168%), while fuel use by Class 8 single-unit gasoline trucks declined from 474 to 62 million gallons (87%) (TIUS/VIUS data). (Note: The absolute values of these fuel use estimates from the TIUS/VIUS may differ from values reported by the FHWA and EIA. However, Figure 1, which is based on EIA data, shows a similar trend of greatly increased use of diesel fuel versus gasoline between 1987 and 2003.)

Two reasons for the growing dominance of diesel fuel use in commercial trucking are shown in Table 3. The reasons are an increase in the diesel truck population and VMT, moderated by reduced fuel consumption per ton-mile. Examples of diesel truck population growth and how the superior thermodynamic efficiency of diesel engines is suited for truck load hauling are cited below, and more complete explanations of the causes and impacts of diesel truck population growth and this fuel economy advantage are presented later in the impacts Section 6 of this report. Also discussed in Sections 5.3 and 10 are how, during these 25 years, operational and regulatory changes took place, leading to a preference for the diesel engine in commercial trucking.

In Table 3, the truck classes are grouped to allow for a focus on the huge difference in growth percentages between the lightest (Class 1 and 2, 10,000 lb or less) and heaviest (Class 8, more than 33,000 lb) categories. Class 8 truck data are separated into the single-unit and combination truck types described above. To help accomplish this purpose, Table 3 does have a Classes 3–7 grouping (which includes medium Classes 3–6 trucks [10,001–26,000 lb] and heavy



Source: Energy Information Administration

FIGURE 1 Changes in Distillate Use, 1987–2003 (Source: EIA 2004)

TABLE 3 Rates of Growth (%) in Number and VMT of All Commercial Diesel Trucks and in Use and Shares of Diesel Fuel by Truck Class, 1977–2002

	Percentage Increase: 1977–2002				
Parameter	1 and 2	3 to 7	8SU	8C	All Classes
Number of diesel trucks	12,600	1,130	256	105	373
VMT by diesel trucks	15,900	974	196	138	235
Diesel fuel use	10,000	932	167	87	135
Share of diesel fuel use growth	11	22	11	56	100

Source: DOC; U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

Class 7 trucks [26,001–33,000 lb]), for which the diesel growth percentages are also large but fall between those of the lightest and heaviest trucks. The extremely high percentage (10,000%) increases in diesel use by light-duty truck Classes 1 and 2 (from a very small 1977 base absolute actual amount of 14 million gallons, shown in Table 2) was generated by the 12,600% increase in the number of these diesel trucks and the 15,900% increase in their annual VMT between 1977 and 2002. Note that the percentage growth in diesel fuel used in Classes 1 and 2 is only 64% of the VMT growth, indicating the higher thermodynamic efficiency of light-duty truck diesel engines over truck gasoline engines. This significantly lower percentage increase in fuel use, in comparison with the percentage increase in VMT, also reflects steadier speeds and the commensurate improvement in fuel efficiency achieved when travel is on limited-access, no-stop-light, no-stop-sign Interstates, even when the same technology is used. The substantially lower (but significant) percentage (932%) increase in diesel fuel use by Class 3–7 trucks shown in Table 3 was generated by the lesser but significant increases of 1,130% in the number of these diesel trucks and of 974% in their VMT. However, the contributions of light-duty trucks and Class 3−7 trucks to the overall growth in the annual actual gallons of diesel fuel used during this period is estimated in Table 2 to be only 11% and 22%[3] (2.9 billion gallons), respectively, as a result of the low 1977 base uses of diesel fuel.

Similarly, within Class 8, single-unit truck fuel use increased by 167% versus the increase in fuel use by Class 8 combination trucks of 87% for the same period. The estimated Class 8 single-unit share of the overall diesel fuel use growth was only 11%, in contrast to 56% for Class 8 combination trucks. This difference was due to the latter's far higher 1977 base fuel use (8.12 billion gallons is 9.4 times greater than 867 million gallons) and the increase of 7.11 billion gallons during this period caused by a larger increase in the VMT by diesel combination trucks (138%, from 37 to 89 billion), rather than an increase in the number combination trucks (105%, from 642,000 to 1,317,000 trucks), which translates into a 17% increase in miles per truck. Such has not been the case for either Class 8 single-unit diesel trucks

---

[3] Our national total TIUS/VIUS fuel use estimates are consistently lower than motor–fuel-tax–based values compiled by the FHWA. Our TIUS/VIUS CHCT share estimate is 11%. The differences are not resolved.

or Class 3−7 trucks, both of which had greater percentage increases in the numbers of trucks than VMT over this period, as shown in Table 3.[4]

In a related University of Minnesota/California State University study using VIUS and TIUS data, heavy-truck (>26,000 lb), long-haul (>200 mi) vehicle miles were found to have increased by 340% (equivalent) to an estimated 65 billion miles between 1977 and 1997, while short-haul miles of these trucks increased by only 42% (equivalent) to an estimated 17 billion miles (<50 mi). Although total miles data for that study's heavy-truck regional operating ranges (50–200 mi) were not given, the percentage shares of 50–200-mile operations of overall total miles held steady at 38% for private carriage, while >200-mile hauls increased from 26% to 34%. Furthermore, the regional for-hire miles share decreased from 30% to 18%, versus a long-haul share increase from 53% to 76% for the period. These trends in increased long-distance travel, together with an increase in diesel truck population, likely contributed to the growing dominance of diesel fuel use by heavy trucks during this period (Burks et al. 2004b).

4.2 INCREASES IN DIESEL TRUCK POPULATION

4.2.1 Diesel Engine versus Gasoline Engine Trucks

Even though Class 8 combination trucks dominated diesel fuel use growth, important increases also occurred in the market share of diesel engines versus gasoline engines for powering lighter-class trucks and Class 8 single-unit trucks between 1977 and 2002. Figure 2 shows that while the market share of diesel Class 8 combination trucks (truck and trailer), in comparison with the market share of comparable gasoline trucks, increased from 95.2% to 99.9% during the period, the other truck groupings also experienced dramatic trends toward increased diesel truck populations. Clear dominance of diesel use over gasoline use was achieved in Classes 3–7, with an increase from 11.2% to 72.5%, and the dominance of diesel over gasoline increased from 64.7% to 97.4% for Class 8 single-unit trucks. The dominance of gasoline in commercial trucking continued only in light-truck Classes 1 and 2, but even there, diesel's share increased from 0.2% to 10.2% (TIUS/VIUS data).

4.2.2 Single-Unit versus Combination Diesel Trucks

Although the heaviest Class 8 combination trucks are the primary reason for diesel fuel use in commercial trucking, they were not the fastest-growing truck population from 1977 through 2002. Table 4 indicates that the growth of Class 2 diesel light trucks was huge — 17,000% — versus 105% for Class 8 diesel combination trucks, and that this growth advantage

---

[4] Note that this discussion is on *diesel* trucks, not all trucks. Later (Section 5.2.3, Table 9), this report shows that the annual miles per Class 3–8 single-unit truck *rose* in the 1977–2002 period. The annual miles per diesel truck dropped, but diesel trucks were driven for far longer distances (far more miles) per year than gasoline trucks. Also, shown later (see Section 5.1.1, Table 6; also see Section 9, Table 19, which shows 1982–2002 VMT comparisons), the strong shift to diesel power among single-unit trucks led to an overall increase in annual miles per truck averaged across both gasoline and diesel power.

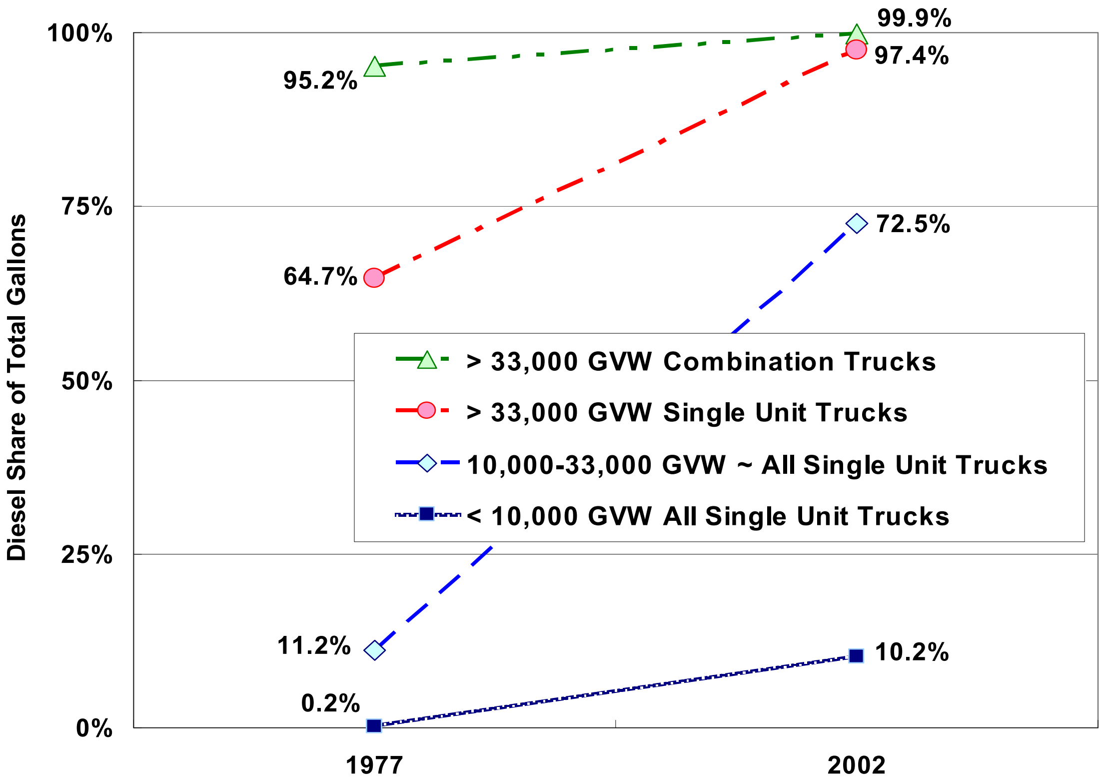


FIGURE 2 Diesel Share of All (Diesel and Gasoline Combined) Commercial Trucks, 1977–2002 (Source: TIUS/VIUS data)

also held for absolute numbers of trucks, at 800,000 versus 675,000. Similarly, when the fastest-growing Classes 1–8 single-unit trucks were added and compared with Class 8 combination and minor amounts of Class 6 and 7 combination trucks, the growth of single-unit trucks in terms of percentages (1,047% versus. 101%) and absolute numbers (2.83 million versus 680,000) were significantly higher, illustrating that in terms of the truck manufacturing industry (and, of course, diesel engine manufacturing), single-unit diesel trucks had much greater growth. In fact, even if light-duty Class 2–5 trucks are excluded, the number of single-unit Class 6–8 trucks grew by 1.09 million units (456%), far exceeding the combination truck numbers above.

4.2.3 Single-Unit Diesel versus Gasoline Trucks

This commercial single-unit diesel truck comparison also holds up versus single-unit gasoline trucks in these classes when one compares their respective trends in Tables 4 and 5. Although Class 2 gasoline commercial trucks had the most absolute growth (1.77 million), this growth was only 71% because it was from a high base of 2.48 million in 1977. In addition, when average decreases of 52% for Class 3–8 gasoline single-unit trucks are offset against Class 2 growth, total Class 2–8 gasoline truck growth for the period is only 423,000 or 8%, versus the growth of diesel Class 2–8 single-unit trucks of 2.57 million or 966%.

TABLE 4 Growth in Population of All Commercial Diesel Trucks by Truck Class and Type, 1977–2002

	Estimated Number of Diesel Trucks			
Truck GVW Class and Type	1977	2002	Total Change	% Change
1SU	3,700	259,900	256,200	6,924
2SU	4,700	805,200	800,500	17,032
Light-duty total	8,400	1,065,100	1,056,700	12,580
3SU	7,100	358,900	351,800	4,955
4SU	4,500	171,100	166,600	3,702
5SU	10,400	171,200	160,800	1,546
6SU	30,900	463,900	433,000	1,401
7SU	35,500	252,300	216,800	611
8SU	173,400	617,100	443,700	256
Class 3–8SU total	261,800	2,034,500	1,772,700	677
Class 1–8SU total	270,200	3,099,600	2,829,400	1,047
Class 2–8SU total	266,500	2,839,700	2,573,200	966
6C	9,400	9,600	200	2
7C	20,200	23,500	3,300	16
8C	641,700	1,317,000	675,300	105
Combination total	671,300	1,350,100	678,800	101
Total	941,500	4,449,700	3,508,200	373

Source: DOC; U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

TABLE 5 Population Changes in All Commercial Gasoline Trucks by Truck Class and Type, 1977–2002

Truck GVW Class and Type	Estimated Number of Gasoline Trucks			
	1977	2002	Total Change	% Change
1SU	5,745,500	7,351,500	1,606,000	28
2SU	2,477,800	4,244,300	1,766,500	71
Light-duty total	8,223,300	11,595,800	3,372,500	41
3SU	624,500	464,900	–159,600	–26
4SU	296,600	136,700	–159,900	–54
5SU	479,900	119,100	–360,800	–75
6SU	729,700	303,600	–426,100	–58
7SU	263,700	111,300	–152,400	–58
8SU	167,600	83,300	–84,300	–50
Class 3–8SU total	2,562,00	1,218,900	–1,343,100	–52
Class 1–8SU total	10,785,300	12,814,700	2,029,400	19
Class 2–8SU total	5,039,800	5,463,200	423,400	8
6C	18,900	1,500	–17,400	–92
7C	22,300	600	–21,700	–97
8C	102,00	4,700	–97,300	–95
Combination total	143,300	6,800	–136,500	–95
Total	10,928,640	12,821,300	1,892,700	+17

Source: DOC; U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

This page intentionally left blank.

5 PROBABLE FACTORS CONTRIBUTING TO DIESEL DOMINANCE IN CARGO-HANDLING COMMERCIAL TRUCKING

The TIUS/VIUS, EIA, and FHWA data in prior sections (i.e., the data in tables with 1977 as the starting point of the measurement period) were for all commercial trucking. Thus, in addition to CHCTs, the data included trucks without any significant amount of cargo weight (e.g., pizza delivery trucks, transmission-line repair trucks, real estate vans). This is because cargo weight information was not available in 1977. Sections 5–11, however, focus on CHCTs — trucks carrying 200 lb or more of cargo — from sample and population data from the TIUS/VIUS 1982–2002 period.[5] They examine the factors that probably contribute to, and the efficiency and fuel consumption that result from, the growing diesel dominance in CHCTs. Research findings on gasoline versus diesel engine operating characteristics and the impact of major national legislation, regulatory and demographic changes, infrastructure improvements, and resultant corporation operational requirements on CHCTs are also assessed by using the TIUS/VIUS sample and population data.

Given all of the changes that have taken place in both overall commercial trucking and, in particular, CHCTs, two important questions arise. First, why did they happen? Second, what are the national implications of these changes? This section answers the why; the next section analyzes the implications.

5.1 TECHNOLOGICAL ADVANTAGES

The previous section discussed how Class 2–8 diesel trucks increased their dominance over gasoline trucks in population, fuel use, and VMT. Although the rates of diesel fuel increase were highest in straight trucks, combination trucks increased their aggregate diesel fuel use more than straight trucks because of slower, but nevertheless significant, growth on top of an already-high share of diesel fuel use. A contrast that was observed was a decreasing length of haul for diesel straight trucks (not to be confused with the average for all straight trucks), compared to an increasing length of haul for combination trucks.

There are very definite technological advantages that have led to the almost total dominance of diesel trucks in long-distance trucking and the pervasively growing dominance of these trucks in both medium-distance and medium-weight truck movements.

5.1.1 Basic Engineering Design and Performance

The advantages of spark-ignition gasoline engines are high horsepower (work done over time) at a high engine speed, producing quick acceleration. They are usually achieved by using a

---

[5] Additional criteria were also used in selecting the “sample” population and “total” population of TIUS 1982 and VIUS 2002 data used in these analyses. Appendix A lists these criteria.

short-stroke engine design[6(a)] and gearing to facilitate a quick increase in speed. A gasoline engine may be appropriate for personal-use trucks (where acceleration seems to matter) or lightly loaded light-duty commercial vehicles (Classes 1–2B) with short-distance patterns of use, which deal with the frequent stop-and-go traffic found in central cities and their surrounding metropolitan areas. It is not appropriate for the fast-growing, long-distance intercity movements and medium-distance movements described above. On the other hand, diesel engines, which generally have a long-stroke engine design with high torque at low engine speed and a "many-speed" transmission (about 10–16 or more speeds on heavy-duty trucks, which are required to move a heavy load from a dead stop),[6(b)] are very appropriate for these long- and medium-distance movements of primarily heavy cargos. For these, quick acceleration is not important, but the ability to travel over long distances hauling a heavy load with the engine in its most efficient operating range (resulting in significantly higher powertrain efficiency) is important. Table 6 illustrates how the vast majority of VMT generated on trips longer than 50 miles by truck in Classes 3–8 are diesel-powered, not gasoline-powered. The fuel use and truck population data in Tables 2, 4, and 5 showed an overwhelming expansion of these single-unit trucks. Diesel's share of the longer trips by single-unit trucks greatly increased between 1982 and 2002.

In addition, diesel engines are most favored for powering heavy Class 8 combination trucks and their cargoes over long distances because they excel at producing hauling power, with the engine operating at a much lower rpm than a gasoline engine. A diesel engine of a given displacement will, in general (due to its longer stroke and higher compression ratio), have a higher torque value at a low rpm than an equivalent-displacement (short-stroke) gasoline engine.[6(c)] Diesel engines tend to operate in a lower rpm range than equivalent-displacement gasoline engines, and this fact may also contribute to their durability advantage over gasoline engines (aside from their being designed to withstand higher compression ratio, greater thrust, and more vibrations).

The following excerpt explains the extent of the fuel efficiency, power, and torque advantages of diesel engines over gasoline engines.

> If it takes six molecules of diesel to idle the engine, the fuel delivery system is free to deliver precisely six molecules of diesel, with no waste. No vacuum is thrown away, for the engine will take in all the air it can get, and burn only what is required to ignite six molecules of #2 diesel. There is no need for an ignition system. Compression ignites the fuel. Diesels run a much higher compression ratio than gas engines, over 20-1, and the greater the compression ratio the more power [torque] can be extracted from the fuel. The very high temperature process is inherently very clean in terms of hydrocarbon and other forms of air pollution, with the exception of nitrogen and particulate matter. Diesels are very strong torque producers, which explains their popularity in trucks and heavy equipment.[7]

---

[6] (a) "Diesel Engine Characteristics," http://cars.about.com/od/dieselvehicles/a/What_is_diesel.htm, (b) "Output Limit," http://en.wikipedia.org/wiki/Four-stroke_cycle, (c) "Undersquare," http://en.wikipedia.org/wiki/Stroke_ratio. All accessed Jan. 5, 2009.

[7] Adalgeirr, 2000, *Diesel,* comment on web page, The Everything Development Company, July 31, http://everything2.com/?node=diesel. Accessed Jan. 6, 2009.

TABLE 6 Single-Unit Gasoline Versus Diesel CHCTs: Cargo TMT and VMT per Truck by Medium and Heavy Truck Class, 2002

		Gasoline Engines		Diesel Engines		Diesel Percentage Advantage vs. Gasoline (%)	
Single Truck Class	Usual Area of Operation (mi)	Cargo TMT/Truck	VMT/Truck	Cargo TMT/Truck	VMT/Truck	Cargo TMT/Truck	VMT/Truck
3	≤50	14,006	9,386	24,606	15,790	75.7	68.2
	>50	25,622	15,366	33,779	20,737	31.8	35.0
	All	16,130	10,480	27,419	17,307	70.0	65.1
4	≤50	20,048	7,516	45,326	18,612	126.1	147.6
	>50	37,900	13,774	78,724	29,507	107.7	114.2
	All	22,342	8,320	54,081	21,468	142.1	146.0
5	≤50	24,921	7,811	51,572	16,788	106.9	114.9
	>50	42,355	13,178	59,172	21,051	39.8	60.0
	All	28,881	9,030	53,703	17,983	85.9	99.1
6	≤50	27,561	4,870	66,594	15,798	141.6	224.4
	>50	49,813	10,460	113,895	27,896	128.6	166.7
	All	30,095	5,507	79,231	19,030	163.3	245.6
7	≤50	29,282	3,519	74,091	12,673	153.0	260.1
	>50	73,737	8,861	143,074	23,622	94.0	166.6
	All	32,292	3,881	92,737	15,632	302.8	302.8
8	≤50	31,726	2,735	273,529	17,692	759.0	546.9
	>50	47,312	3,155	441,538	27,168	833.2	761.1
	All	32,751	2,762	307,646	19,617	839.3	610.2

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

Also with regard to the diesel engine's compression-ignition process, the Diesel Technology Forum (2001) has noted that diesels achieve higher thermal efficiency, thus improving fuel economy over that of gasoline and all other spark-ignition engines (compressed natural gas [CNG], liquefied natural gas [LNG], and propane), which burn fuel at lower temperatures under low compression. DOE estimates this higher peak thermal efficiency to be 45% versus gasoline engine's 30% (DOE 2003). However, a drawback of the diesel engine is that it is heavier than an equivalent displacement gasoline engine because of its "overbuilt" design, which reduces the net cargo capacity of diesel trucks within their GVW ratings (Gold 2009).

These fuel-volume efficiency,[8] thermal-efficiency, torque-producing, and rpm-reducing advantages of diesel engines have increasingly made them the engine of choice for Classes 3–8 during the 1977−2002 period, as indicated in Table 3 and Figure 2. This popularity has led, according to our estimates, to significant advantages in fuel consumption for commercial truck tons shipped for most of the truck classes. These advantages are discussed in the following paragraphs in terms of diesel versus gasoline gallons per laden ton-mile traveled (GPLTMT).

In addition, diesel fuel itself adds to the advantage of using diesel instead of gasoline engines, even for light-duty trucks. For example, because a gallon of diesel has about 138,700 Btu of energy but a gallon of gasoline has only 125,000 Btu, it takes about 11% more gasoline to equal the energy output of diesel fuel, making diesel engines more efficient per gallon of fuel burned. Also, because diesel engines use the direct fuel-injection method (fuel injected directly into cylinder), which is more efficient than the port fuel-injection setup in gasoline engines (gasoline is mixed with incoming air in the intake manifold), the diesel system has little wasted or unburned fuel.

Besides these fuel efficiency advantages, diesel engines offer greater durability than gasoline truck engines because of their overbuilt (relative to gasoline engines) design, required to endure the higher-pressure and higher-temperature environment associated with the diesel combustion cycle (Gold 2009). Thus, *Truck Trend* (2002) cites the ability of large diesel engines to “log 100,000 miles a year for years on end, routinely haul heavy loads, and may have to idle for days at a time.” In addition, comparing diesel pickup truck engines to their heavy-truck counterparts, the article describes them as “mini big-rig engines.” It points out that “the average gas engine is good for only around 125,000 miles before needing a rebuild and isn’t designed to constantly carry a heavy load. A diesel can go more than three times this amount before needing an overhaul.”

The advantage of diesel engines in terms of durability is supported by the data on Class 3−8 single-unit (straight) trucks in Table 6, which indicate not only huge percentage advantages based on VIUS 2002 data for various trip lengths and overall 2002 movements of Class 8 heavy single-unit trucks in cargo TMT per truck and VMT per truck, but also notable Class 3−7 diesel truck percentage advantages for these measures by overall single-unit class. Furthermore, the very large percentage increase in miles of use of diesel engines increases in most cases as the medium and heavy single-unit truck class increases in size from Classes 3 through 8. In addition, there are consistent increases for the categories of ≤50 miles and >50 miles area of operation.

Also, 2002 data in Table 7 show that in all but Class 8 single-unit trucks and in Class 3 single-unit trucks that make trips of ≤ 50 miles, gasoline trucks carry more cargo weight per truck than diesel trucks for all of the mileage categories of medium and Class 7 heavy trucks. This indicates that the very large advantages in Class 3–7 diesel engine trucks are due to the far

---

[8] Because diesel fuel contains about 11% more energy per unit volume than gasoline, smaller tanks can be used for diesel vehicles, or more fuel can be held in the same size of tank.

TABLE 7 Single-Unit Gasoline Versus Diesel CHCTs: Cargo Tons per Truck by Medium and Heavy Truck Class, 2002

	Cargo Tons per Truck			
Single-Unit Truck Class	Usual Area of Operation (mi)	Gasoline Engine	Diesel Engine	Gasoline % Advantage (Disadvantage)
3	≤50	1.5	1.6	(6.7)
	>50	1.7	1.6	6.3
	All	1.5	1.6	(6.7)
4	≤50	2.7	2.4	12.5
	>50	2.8	2.7	3.7
	All	2.7	2.5	8.0
5	≤50	3.2	3.1	3.2
	>50	3.2	2.8	14.3
	All	3.2	3.0	6.7
6	≤50	5.7	4.2	35.7
	>50	4.8	4.1	17.1
	All	5.5	4.2	31.0
7	≤50	8.3	5.8	43.1
	>50	8.3	6.1	36.1
	All	8.3	5.9	40.7
8	≤50	11.6	15.5	(33.6)
	>50	15.0	16.3	(8.7)
	All	11.9	15.7	(31.9)

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

greater distances that can be driven with these durable, energy-efficient engines, not any cargo-weight-carried advantages, like those in single-unit Class 8 trucks. The mileage data help to explain why diesel dominance has not only grown in single-unit heavy Class 7 and 8 trucks, but also in single-unit medium diesel trucks, which, in 2002, far outnumbered single-unit gasoline trucks and used significantly more fuel in Class 3−6 trucks, as shown in Tables 2, 4, and 5. This preponderance of diesel engines in Class 3−8 *single-unit* trucks adds to the total dominance of Class 8 *combination* diesel trucks over Class 8 combination gasoline trucks shown in those tables and Figure 1 and illustrates how diesel engines have completely taken over the medium and heavy commercial trucking markets. On the other hand, the decline in cargo per single-unit truck in most classes has had a negative impact on the operational fuel efficiency (i.e., gallons per cargo ton-mile traveled [GPCTMT] in most classes) of both diesel and gasoline trucks, even as their technological fuel efficiency has been improving. This phenomenon will be discussed is Section 5.2.3 and Section 6.

5.1.2 Comparative Engine Improvements

Many non-engine-related improvements in fuel efficiency in medium and heavy trucks with both diesel and gasoline engines have been adopted and used during the 25 years between 1977 and 2002. These include reductions in aerodynamic drag, tire rolling resistance, and vehicle mass. Such technological improvements are not examined in this report. The TIUS/VIUS surveys are not suited for investigating or isolating their effects.

In addition, a 1998 EPA study (Browning 1998a) conducted dynamometer readings that found similar improvements in fuel economy (0.5 to 1.3 miles per gallon or mpg) in both diesel and gasoline Class 2–8 truck engines due to electronic fuel injection from 1987 through 1996 (Browning 1998b). The EPA study also noted that these generic fuel economy improvements began in 1982 in gasoline trucks when electronic fuel injection systems were introduced (Browning 1998a). On the other hand, charge-cooled diesel engines were introduced in 1982, electronic diesel control (EDC) electronic fuel injection was developed in 1987, and turbocompound diesel engines were first offered in 1991 (Scania Trucks undated; Kelley 1993). Nevertheless, only gradual market acceptance of these gasoline and diesel truck engine improvements has been noted (Browning 1998a; Vyas et al. 2002). For single-unit trucks, large numbers of older gasoline and diesel trucks on the road throughout the introduction and market penetration periods (Vyas et al. 2002) of the new technologies somewhat diluted total fleet impacts of comparative improvements in diesel engines caused by a switch from gasoline to diesel trucks between 1977 and 2002.

Hence, the main technological reasons favoring the growing dominance of diesel engines and fuel use in commercial trucking appear to be the basic engineering design advantages cited in the previous subsection describing durability advantages of commercially successful diesel engines. Although the fuel efficiency advantages are certainly also valuable, they appear to be less important than durability.

5.2 INFRASTRUCTURE IMPROVEMENTS, DEMOGRAPHIC CHANGES, OPERATIONAL REQUIREMENTS, AND REGULATORY CHANGE

5.2.1 Infrastructure Improvements

The Federal-Aid Highway Act of 1956, for which the U.S. Senate passed a resolution commemorating it in April 2007 (Goldstein 2006), resulted in large part from participation of then Lt. Col. Dwight D. Eisenhower in the U.S. Army’s first transcontinental motor convoy from Washington, D.C., to San Francisco in 1919. The reasoning behind how this experience can be considered “the genesis of Eisenhower’s vision for a 40,000-mile network of strategically designed Interstate highways” was recently described in the following way:

> The 3,251-mile trip, which driver teams today routinely make in about four days, took 62 days — only five days behind schedule. The convoy endured mishaps that included mechanical breakdowns, trucks and other equipment crashing through

> wooden bridges, slippery roads, conditions described as "gumbo," and countless vehicles stuck in mud or sand (Schultz 2006).

The motivation provided by this trip, plus General Eisenhower's experience as supreme allied commander during World War II, during which he saw Germany's network of modern roads and "the wisdom of broader ribbons across the land" (Eisenhower 1967), as he described them, led him to champion the interstate highway system. Highlighting the system in both his 1954 and 1956 State of the Union Addresses, the Act was passed in 1956 after a 1955 bill was defeated (Schultz 2006). The Act is given credit for having "…changed the very nature of the trucking industry, which had consisted mainly of local delivery services usually restricted to trips of not more than 250 miles" (Schultz 2006).

It authorized what was to become the Interstate highway system of 42,700 miles. It required superhighway standards for all of these highways. The Act also made the truck mode attractive for its point-to-point delivery capability in short time and set the stage for diesel engine domination in heavy-duty trucking. With 40,000 miles of these high-quality Interstates constructed by 1980, the opportunity to conduct the long-distance, steady, high-speed operations that maximize the efficiency of heavy-duty Class 7 and 8 diesel trucks was provided to both for-hire operations (cargo owned by customer) and private-carrier operations (cargo owned by carrier), as well as single-unit and combination trucks. These economic and operational efficiencies resulted from the high standards that were adopted for the Interstate highway system:

> Access to all Interstates was to be fully controlled. There would be no intersections or traffic signals. All traffic and railroad crossings would be grade separated, requiring the construction of more than 55,000 bridges. Interstates were to be divided and have at least four wide traffic lanes (two in each direction) and adequate shoulders. Curves were to be engineered for safe negotiation at high speed, while grades were to be moderated, eliminating blind hills. Rest areas were to be conveniently spaced. Each Interstate was to be designed to handle traffic loads expected 20 years after completion (Cox and Love 1996).

The gradual construction of these 42,700 high-quality Interstates from the 1950s through the 1970s probably contributed strongly to heavy Class 8 diesel trucks reaching the already dominant position in commercial trucking in 1977 that is shown in Figure 2.

A recent Internet business reference encyclopedia article, citing this legislation's improvement of the national highway system, identified it as a major factor in the growth of long distance trucking into shipments previously carried by rail, noting that:

> Prior to the 1950s, most of the nation's long distance freight shipments were made by rail, and trucks were used primarily to provide local delivery to and from rail stations. Unloading and reloading cargo for rail to truck transfers increased the cost of moving goods and provided an economic incentive for shippers to switch to long distance, over-the-road transport. The percentage of freight deliveries made by truck increased from about 17 percent of all deliveries in 1950 to almost 25 percent by the end of the decade (Thomson Corporation undated).

Oak Ridge National Laboratory analysts estimate that the share of commercial transport energy use of the major freight modes accounted for by trucking rose from 53% in 1970 to 71% in 2000, with rail's share dropping by more than half (Davis and Diegel 2006; Figure 3).

5.2.2 Demographic Changes

The Thomson Corporation article also noted how "another national phenomenon, suburban growth, increased the importance of trucks to American life." The shorter distances required of trucks by concentrated populations in cities were being expanded, increasing the need for fuel efficient, durable diesel engines:

> Decentralized, suburban lifestyles required the kind of flexible freight transport trucks provided. Trucks made suburban development possible, and suburban development increased the demand for trucks. Trucks served the construction industry as it built suburbs; trucks carried household possessions as families moved into the suburbs. Trucks also served the businesses that moved from the central city to outlying areas (Thomson Corporation undated).

Other studies focused on the magnitude of these changes through population data. One paper noted that "in the 1950s, 57% of standard metropolitan area residents lived in the central cities, compared to 37% in 1990." It stated that:

> This outward trend continued through the 1990s with the development of "edge cities" in previously residential and low-density, scattered residential patterns reaching out to rural-urban fringe areas. These patterns represent a redistribution of metropolitan area populations to suburbs and exurbs, a trend that has been the dominant pattern of the spatial location of the U.S. population in the past half-century (Bayok et al. 2002).

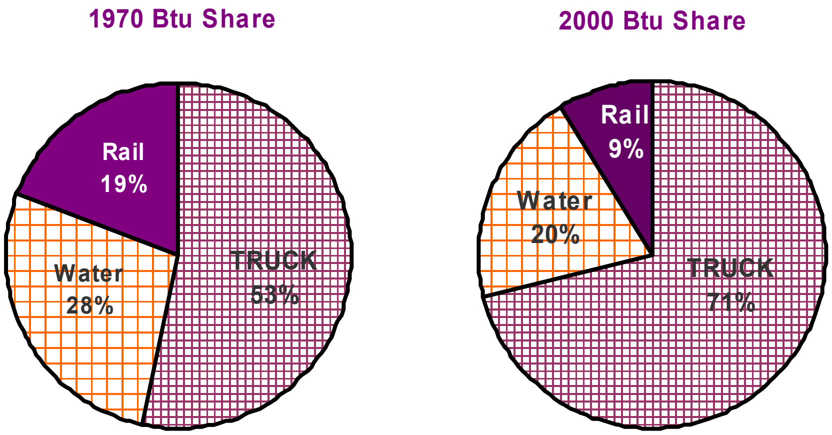


FIGURE 3 Share of Energy Estimated to Be Used by Truck, Rail, and Water Transport (Source: Davis and Diegel 2006)

Even more detail is provided in an article (Liechenko 2001) discussing the steadily declining share of central city populations in the overall populations of metropolitan areas nationwide and in major geographic regions, as shown in Table 8. These declining central city shares led to research on the growth of suburbs, with the label "edge cities" being given to those suburbs that had gradual growth and

> over approximately 30 years have transformed from rural or residential locations to bustling mixed-use destinations having at least 5 million square feet of leasable office space, at least 600,000 square feet of leasable retail space, and a larger daytime population than nighttime population (Mikelbank 2006; Garreau 1991).

There was also a focus on suburbs with explosive, rapid growth. A group of suburban locations were labeled "boomburbs."

> To be a Boomburb, a city must meet the following threshold conditions: (1) they have a population of at least 100,000, (2) they are not the largest city in their metropolitan area, and (3) they have experienced at least 10 percent growth between each decennial census since 1950 (Mikelbank 2006; Lang and Simmons 2001).

5.2.3 Resultant Operational Requirements

The availability of Interstates and population shifts contributed to an evolving America, with changing operating requirements for trucks serving metropolitan areas with increasingly large and dispersed suburbs at the expense of central cities. The data discussed below show that the needs of these areas were best met by durable diesel engine CHCTs in these new operating environments. The greater distances being driven annually in 2002 versus 1977 by both single-unit and combination trucks are shown in Table 9 by roadway category and overall. For single-

TABLE 8 Aggregate Central Cities' Share of Metropolitan Area Populations, by Region

Region	1970	1980	1990	1997
Midwest	0.42	0.36	0.34	0.32
Northeast	0.45	0.41	0.40	0.40
South	0.43	0.38	0.34	0.31
West	0.41	0.38	0.37	0.37
Total	0.43	0.38	0.36	0.35

Sources: Leichenko (2001); U.S. Bureau of the Census (2000a,b); U.S. Department of Housing and Urban Development (1997)

TABLE 9 Changes in Single-Unit and Combination Class 3–8 CHCTs: Total Annual VMT, Populations, and VMT per Vehicle by Highway Category, 1977–2002

	Millions of Annual VMT					
	Class 3–8 Single-Unit Trucks			Combination Trucks		
Highway Category and Vehicle Data	1977	2002	Percent Increase	1977	2002	Percent Increase
Urban Interstates[a]	3,253	9,119	180.3	7,643	23,921	213.0
Rural Interstates	3,852	8,765	127.5	17,588	45,738	160.1
Other urban streets[a]	13,459	28,465	111.5	10,760	27,214	152.9
Rural other arterial roads	8,548	14,610	70.9	13,613	27,826	104.4
Other rural roads	10,227	14,907	45.8	6,078	14,038	131.0
Total travel	39,339	75,866	92.9	55,682	138,737	149.2
Number of vehicles (10^3)	4,450	5,651	27.0	1,240	2,277	83.7
Average annual VMT per vehicle (all road categories)	8,840	13,426	51.9	44,919	60,939	35.7

[a] Urban travel is defined in this table and its reference sources as travel on all roads and streets in urban places with populations of 5,000 or more. This includes suburban areas.

Sources: FHWA 1997b, 2004

unit trucks, the greatest absolute annual mileage increase from 13.5 to 28.5 billion, or 111%, is in the "other urban streets" category of roads. These are defined by the FHWA as "all roads and streets in urban places with 5,000 or greater population," which includes the growing suburban areas described above. Large percentage increases are also shown for single-unit trucks on urban and rural Interstates and rural arterials, which include high-speed freeways, according to the FHWA (1997a), although their absolute mileage increases have only been about 40% as high as for other urban streets; (i.e., about 6 billion increased annual miles each versus 15 billion increased annual miles for urban streets). Overall, total travel for these trucks increased by 93%, while the number of trucks increased by only 27%. All of these mileage increases on various roadway types resulted in an average annual mileage increase of 52% overall for individual single-unit trucks, from 8,840 to 13,430 miles annually in the 1977–2002 period. This significant operational change and the service demands it put on single-unit trucks substantially increased the need for both the fuel efficiency (to help keep fuel costs from also rising 52%) and superior durability of diesel engines versus gasoline engines (to keep repair costs down). As a result, it was a major contributing factor to the trend illustrated in Tables 4 and 5, which shows replacement of 1977 gasoline engine domination to diesel engine dominance in 2002 for these medium and heavy trucks.

In comparison, combination trucks are shown in Table 9 to have continued to increase their dominance over gasoline engine trucks as a result of the high fuel efficiency and durability demands to cover large increased distances on all road types, averaging a 149% total annual mileage increase overall, which is significantly more than the 93% increase in mileage for

Class 3–8 single-unit trucks (Table 9).[9] There was also a considerably higher percentage increase in the number of combination trucks (84%) versus single-unit trucks (27%).[10] The average VMT per combination truck increased by about 36% to 61,000 annually, versus about 52% for single-unit trucks. The higher increase in VMT per single-unit truck was consistent with the dramatic shift of these trucks from gasoline to diesel powertrains for increased durability, whereas most combination trucks were already durable diesels in 1977. Where diesels had dominated, increases in VMT had to be accomplished by adding trucks; where gasoline had dominated, replacement of low-annual-mileage gasoline trucks with high-annual-mileage diesel trucks allowed increases of total miles of service by single-unit trucks with a much smaller increase in the number of trucks.

Another operating requirement driving this increased demand for all truck miles — diesel-powered miles in particular — was the increase in international trade (which requires the movement of containerized cargo, most of it by truck, to and from U.S. ports) and its growing share of overall U.S. commerce. The share of U.S. international trade grew from 11% of GDP in 1970 to 25% in 1997, and it was forecasted to reach 37% by 2025 (The Road Information Program 2004). For example, the containerized cargo handled at the Port Authority of New York and New Jersey doubled between 1991 and 2002 (Rodrigue 2004), and 87% of import cargo departed by truck (Port Authority of New York and New Jersey 2003). Increased truck movements of containerized cargo to such ports for transportation overseas increased the distances traversed during these shipments by individual trucks above and beyond those that were needed when U.S. markets were primarily domestic, adding to the need for diesel durability.

In addition, another operational change occurring during this period in domestic shipments was lower cargo weights per individual truck type, creating an operational requirement for single-unit trucks to have the superior durability associated with diesel engines to make more trips over given distances. The lesser ability of gasoline-powered trucks to handle such additional trips no doubt accelerated the switch to diesel truck engines in the 1977–2002 period. Although this operational change was made to improve the overall efficiency and reduce the costs of corporate distribution systems by reducing expensive inventories, it undermined the fuel efficiency of these systems in moving cargo. As the next section shows, diesel and gasoline fuel efficiencies per single-unit truck cargo ton-mile traveled did not improve as much as one would expect, given the truck technology improvements in engines, aerodynamics, rolling resistance, and vehicle mass reduction in the 1982–2002 period. A probable contributing factor to less cargo being hauled per single-unit gasoline and diesel truck mile moved, as shown in Table 10, was widespread implementation of a new distribution policy called just-in-time (JIT)

---

[9] Note that this estimate (for both diesel and gasoline combination trucks) comes from a different source than used for Table 3, where the estimate was 138% for only diesel trucks.

[10] These estimates are for total trucks, both diesel and gasoline combined, in contrast to Tables 3–5, where diesel and gasoline trucks are shown separately. There was a huge shift from gasoline to diesel in Class 3–8 straight trucks, but not a large increase (i.e., 27%) in the number of such trucks.

TABLE 10 Percent Change in Cargo Weights by Truck Class and Usual Operating Area

		1982 and 2002 Cargo Tons[a] per Gasoline and Diesel Truck					
	Usual Area	Gasoline Engine		Percent Decrease (−) or Increase (+)	Diesel Engine		Percent Decrease (−) or Increase (+)
Truck Class	of Operation (miles)	1982	2002	1982–2002	1982	2002	1982–2002
1SU	<=50	0.6	0.5	−16.6	0.6	0.5	−16.6
	>50	0.6	0.7	16.6	0.5	0.6	16.6
	All	0.6	0.6	0.0	0.6	0.5	−16.6
2SU	<=50	1.3	1.0	−23.1	1.2	1.0	−16.6
	>50	1.3	1.1	−15.4	1.4	1.2	−14.3
	All	1.3	1.1	−15.4	1.3	1.0	−23.1
3SU	<=50	2.2	1.5	−31.8	1.6	1.6	0.0
	>50	2.2	1.7	−9.1	1.9	1.6	−15.8
	All	2.2	1.5	−31.8	1.8	1.6	−10.5
4SU	<=50	3.2	2.7	−15.6	2.4	2.4	0.0
	>50	3.0	2.8	−6.7	2.7	2.7	0.0
	All	3.1	2.7	−12.9	2.5	2.5	0.0
5SU	<=50	3.9	3.2	−17.9	3.0	3.1	3.3
	>50	3.9	3.2	−17.9	3.3	2.8	−15.1
	All	3.9	3.2	−17.9	3.2	3.0	−6.3
6SU	<=50	6.0	5.7	−5.0	4.8	4.2	−12.5
	>50	6.0	4.8	−20.0	5.1	4.1	−19.6
	All	6.0	5.5	−8.3	4.9	4.2	−8.9
7SU	<=50	8.5	8.3	−2.6	7.0	5.8	−17.1
	>50	8.4	8.3	−1.2	7.0	6.1	−12.9
	All	8.4	8.3	−1.2	7.0	5.9	−15.7
8SU	<=50	13.8	11.6	−15.9	16.4	15.5	−5.5
	>50	12.3	15.0	22.0	18.9	16.3	−13.8
	All	13.5	11.9	−11.9	17.2	15.7	−8.7
6C	<=50	5.4	§	§	5.2	2.7	−48.0
	>50	§	§	§	4.9	2.3	−53.1
	All	5.4	§	§	5.1	2.5	−51.5
7C	<=50	7.7	§	§	6.6	4.6	−30.3
	>50	§	§	§	5.1	4.7	−7.8
	All	7.6	§	§	6.0	4.7	−21.6
8C	<=50	14.1	§	§	19.3	20.2	4.7
	>50	15.2	§	§	20.1	20.8	3.5
	All	14.4	§	§	19.9	20.6	3.5

SU = single unit; C = combination

[a] All tons rounded to tenths of a ton.

§ = Fewer than 30 records.

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

delivery by the nation's corporations.[11] This policy turned these trucks into a fleet described as "America's rolling warehouses" (The Road Information Program 2004).

This study cites an FHWA report, which describes the recent evolution of American businesses from

> "manufacture-to-supply" or inventory based logistics ("push" logistics) to "manufacture-to-order" or replenishment-based ("pull" logistics). The latter relies less upon expensive inventory and more on accurate information and timely transportation to match supply and demand (FHWA 2002).

The JIT concept was applied in the early 1900s to the ordering of raw materials by the Ford Motor Company, as described by Henry Ford in 1922:

> "We have found in buying materials that it is not worthwhile to buy for other than immediate needs. We buy only enough to fit into the plan of production, taking into consideration that state of transportation at the time. If transportation were perfect and an even flow of materials could be assured, it would not be necessary to carry any stock whatsoever. The carloads of raw materials would arrive on schedule and in the planned order and amounts, and go from the railway cars into production. That would save a great deal of money, for it would give a very rapid turnover and thus decrease the amount of money tied up in materials. With bad transportation one has to carry larger stocks" (Ford 2005).

Until the 1980s, Ford and others were able to implement this JIT concept to some extent, given the limitations of the same transportation systems that inspired President Eisenhower to effectively champion the Interstate highway system. However, with this and other improvements in the nation's infrastructure, major new applications of the JIT concept throughout manufacturing processes became possible. Improved computer and telecommunications systems combined with the new highway systems to help this concept overcome the limitations experienced by Henry Ford. By the late 1980s and early 1990s, lean inventories and JIT delivery were "really being implemented" (Haight 2004).

This implementation, while especially strong in the auto manufacturing industry and its suppliers (Bukey and Davies 1991), has been very widespread among industries. It is cited as having "transformed the auto industry" (Foss 2006), but it is also depended upon by food processors, who "rely on just-in-time (gasoline[sic]-based) delivery of fresh and refrigerated food" (Church 2005); by the home-building industry to prevent theft and weather exposure (Foss 2006); and by General Electric Corporation at its 300 multi-industry, worldwide logistics

---

[11] Although government research has also identified JIT distribution (Rodrigue 2004), with its more frequent trips with partially full cargo loads to eliminate expensive inventories as a probable cause of the reduced Class 3–8 single-unit truck cargo weights in Table 10, related university research using TIUS/VIUS data also cites decreasing cargo densities as a potential logical cause. The university researchers indicate that such decreasing cargo densities may also have resulted from the economy's movement away from heavy manufacturing toward lighter goods, but they further indicate that their data did not "reveal" the relative importance of the two factors (Boyer and Burks 2006).

centers (Haight 2004). Many other industries were striving toward the auto industry's "sequenced delivery" systems, in which suppliers and auto company customers synchronized production to achieve JIT delivery and the goal of zero inventory, resulting from "supplier pipelines which are only hours long as opposed to days or even weeks that we used to experience," according to two auto industry logistics experts (Bukey and Davies 1991). During the early implementation period in the 1980s and 1990s, the prevailing corporate distribution philosophies were that there "wasn't a plan for every part, it was every part every day" and "let's do everything just-in-time," according to two general industry observer participants (Haight 2004).

The effect maximized JIT delivery can have on reducing cargo per truck and increasing the number of trips and resulting fuel consumption, both in the aggregate and in fuel used per cargo ton-mile traveled, is evident at a Ford Motor Michigan plant where parts aggregated from multiple suppliers at a nearby logistics center are ordered hourly and delivered by trucks 40 to 50 times daily (Sullivan 2005). Although this is still a current and increasingly sophisticated practice in the auto industry because of its particular needs, other industries have fine-tuned this delivery strategy to where "companies are going to try to do just-in-time with only the things that really make sense to do just-in-time" (Haight 2004). Such adjustments (from "run every part every day" to "in some cases you may run parts every other day"; see Haight 2004), can increase shipment sizes, reverse the lower cargo weight trend shown in Table 10, better realize fuel efficiencies of cargo movements by diesel trucks , and reduce U.S. petroleum use by both diesel- and gasoline-powered trucks. These JIT delivery operations have already helped accelerate the shift to more durable and energy-efficient diesel trucks to help deal with the increases in miles driven shown in Table 9. The more judiciously JIT is applied, the greater the savings in the fuel efficiency of diesel trucks. The increases in the price of diesel fuel (and gasoline) in recent years are probably also causing some reevaluations and adjustments of JIT policies.

In addition, another phenomenon called "big box retailing" has occurred in the retailing industry in recent years. It has helped mitigate the negative overall fuel efficiency impacts of JIT delivery policies by improving the routing and load factors of Class 8C trucks. This truck class was the only one in the 1982–2002 period with improved cargo/truck capacity, which increased from 20.8 to 21.4 tons for trips of ≤50 miles and from 20.4 to 21.0 tons for trips of >50 miles (TIUS/VIUS data). Fostered by the Interstate highway system and the growth of suburbs described earlier in this report, this retailing strategy (used by such companies as Wal-Mart, Target, Home Depot, and Circuit City; see Fedrizzi and Rogers 2002), has employed giant distribution centers at strategic locations, plus maximally loaded Class 8C trucks, to supply their retail stores. The Wal-Mart system has been described in multiple articles and provides a good example of how these distribution systems work. One of Wal-Mart's typical 110 distribution centers is about 1 million square feet in size, has the latest in state-of-the-art inventory control and materials handling equipment, and can supply about 150–200 retail stores that are located in a circular pattern around it (Stone undated; Govindarajan and Lang 2002; Solman 2004). Like many "logistics and warehousing centers," it is likely to be located at "strategic interchanges. . . interconnections between north-south and east-west highways. . . primarily Interstates" (Weisbrod 2006). Such Interstates and similar connecting, uncongested four- and two-lane highways are vital to enabling a center's one-day round-trip supply times. Govindarajan and Lang (2002) estimate that these centers are served by the company fleet of 3,000 trucks and

12,000 trailers, with the company consolidating orders into full truckload quantities without incurring inventory costs, because of 24-hour laser-guided conveyor belts and cross-docking techniques that receive goods on one side of the center while simultaneously filling orders on the other side.

Distribution centers supply about 78% of Wal-Mart merchandise sold, with the rest delivered directly to stores from the factory or through vendors and distributors. Interestingly, the factory vendors and distributors may very well service Wal-Mart distribution centers and retail stores on a JIT delivery basis that is far less fuel efficient than Wal-Mart's, by using trucks with far-less-than-truckload quantities. Thus, Wal-Mart and other big-box retailers enjoy the fuel efficiency of a JIT delivery system with their Class 8C private fleet truckloads when many of their suppliers do not and probably use less-than-truckload (LTL) single-unit truck shipments.

5.3 OVERVIEW OF THE IMPACTS FROM INTRODUCING AN IMPORTANT REGULATORY CHANGE

Another factor that almost certainly contributed to diesel dominance (particularly the growing dominance of Class 8 combination diesel trucks) was the federal law (*United States Code* 1982) that gave the trucking industry "permission to run heavier trucks on the nation's major highways, albeit at the cost of sharply higher use and excise taxes" (Associated Press 1982). This law, Title 23, "Highways, Federal Truck Size and Weight Laws," Section 127, "Vehicle Weight Limitations — Interstate System," by facilitating unobstructed growth of the largest Class 8C diesel trucks in interstate commerce, enabled these long-distance heavy trucks to take advantage of their inherent fuel efficiency advantages detailed in the next section. It could be called the "final piece in the puzzle" that literally and legally allowed these truckers to take advantage of the other contributing factors, including basic engineering design and performance, infrastructure improvements, and resultant operational requirements identified earlier in this section as leading to increased use of diesel fuel in all truck classes. Because the data presented in Sections 6–9 are needed to fully illustrate and explain the impacts of the components of this legislation, detailed information on the law is presented later in this report in Section 10.

This page intentionally left blank.

6 IMPACTS OF DIESEL DOMINANCE ON FUEL EFFICIENCY IN CARGO-HANDLING COMMERCIAL TRUCKING

JIT delivery operations were a double-edged sword with regard to CHCT diesel truck contributions to overall commercial trucking aggregate fuel consumption savings. On one hand, they encouraged the use of diesel engines to achieve the durability and energy efficiency that saves petroleum. On the other hand, they reduced a truck's load factor (percentage of full truckload capacity used) and significantly increased the total number of trips, which used more petroleum. Nevertheless, the growing dominance of medium and particularly heavy diesel trucks still substantially improved the overall fuel efficiency of commercial trucking, as is shown later in this section.

6.1 COMPARISON OF METHODS FOR MEASURING FUEL EFFICIENCY

Estimates of how much trucking fuel efficiency improved depend a great deal on the particular measure selected for calculating relative diesel and gasoline truck fuel uses. For example, Table 11 shows significant improvements in mpg in 1982–2002 among both gasoline and diesel engine trucks in most truck classes and how, in most truck classes and most areas of operation, diesel trucks had large (>10%) mpg advantages over their gasoline counterparts. One pair of major exceptions were 1982 and 2002 Class 8 single-unit gasoline trucks with usual operating areas of both ≤50 and >50 miles per trip; these trucks had exceptionally good mpg results when compared with their diesel counterparts, unlike all other medium and heavy classes of gasoline versus diesel trucks. This unusually high mpg may indicate that these gasoline Class 8 single-unit trucks could have some kind of unusual operations or other circumstances associated with them that favored these mpg numbers.

This is particularly so given the gallons per laden ton-mile traveled (GPLTMT) data for both 1982 and 2002 in Table 12. These data provide a similar but inverse calculation for mpg estimates because both of them calculate fuel efficiency in terms of "laden weights," defined as cargo plus vehicle, engine, and accessories weight, rather than in terms of only the cargo weight transported. These comparisons of GPLTMT and subsequent comparisons of GPCTMT did not account for the 11% heating value advantage of diesel fuel. Except for slight gasoline GPLTMT advantages in Class 1 (the smallest of commercial trucks), Table 12 indicates very large diesel GPLTMT advantages over gasoline in every other truck class and area of operation in both 1982 and 2002, ranging from the lowest 13% advantage to the highest 68%. It is important to note the diesel advantage percentages shown in Table 12 are the average percentages of diesel over gasoline per laden (with cargo) ton-mile (in GPLTMT). The 61% advantage in all Class 8C diesel trucks in 1982 was so large that by 2002, very few commercial truck users employed Class 8C gasoline trucks. Furthermore, 2002 Class 8 single-unit diesel trucks had a 33% GPLTMT *advantage* over comparable gasoline trucks, a radically opposite result from the 2002 mpg disadvantage estimates for this truck type in Table 11.

TABLE 11 Diesel Versus Gasoline Weighted Average Miles per Gallon (mpg) by CHCT Class and Usual Area of Operation, 1982–2002

		Weighted[a] Average Miles per Gallon and Percent Change							
		Gasoline Engine (mpg)		Percent Increase (+) or Decrease (–)	Diesel Engine (mpg)		Percent Increase (+) or Decrease (–)	Diesel (Gasoline) Percent Advantage[§]	
Truck Class	Usual Operating Area (mi)	1982	2002	1982–2002	1982	2002	1982–2002	1982	2002
1	≤50	10.40	11.31	+8.8	b	10.75	–	–	(5.2)
	>50	9.97	7.88	–21.0	b	b	–	–	–
	All	10.32	10.01	–3.1	b	10.05	–	–	0.4
2	≤50	8.80	9.56	+8.6	10.93	10.76	–1.6	24.2	12.6
	>50	8.88	9.64	+8.6	9.44	11.22	+18.9	11.9	16.4
	All	8.82	9.58	+8.6	10.20	10.90	+6.9	15.6	13.8
3	≤50	7.23	8.70	+20.3	8.72	10.14	+16.3	20.6	16.6
	>50	7.59	9.05	+19.2	8.67	10.44	+20.4	14.2	15.4
	All	7.30	8.79	+20.4	8.69	10.25	+18.0	19.0	16.6
4	≤50	6.38	8.24	+29.2	8.18	9.63	+17.7	28.2	16.9
	>50	6.41	8.83	+37.8	8.44	9.94	+17.8	31.7	12.6
	All	6.39	8.36	+30.8	8.29	9.74	+17.5	29.7	16.5
5	≤50	6.15	7.40	+20.3	7.87	8.90	+13.1	28.0	20.3
	>50	6.28	7.26	+15.6	8.34	9.30	+11.5	32.8	28.1
	All	6.18	7.36	+19.1	8.08	9.03	+11.8	30.7	22.7
6SU	≤50	5.95	7.03	+18.2	7.21	8.35	+15.8	21.2	18.8
	>50	5.88	7.13	+21.3	7.73	8.83	+14.2	31.5	23.8
	All	5.94	7.05	+18.7	7.44	8.53	+14.7	25.3	21.0

TABLE 11 (Cont.)

		Weighted[a] Average Miles per Gallon and Percent Change							
		Gasoline Engine (mpg)		Percent Increase (+) or Decrease (–)	Diesel Engine (mpg)		Percent Increase (+) or Decrease (–)	Diesel (Gasoline) Percent Advantage[§]	
Truck Class	Usual Operating Area (mi)	1982	2002	1982–2002	1982	2002	1982–2002	1982	2002
6C	≤50	4.60	§	–	5.58	b	–	21.3	–
	>50	§	§	–	6.23	5.98	–4.0	–	–
	All	4.79	§	–	5.95	6.33	+6.4	–	–
7SU	≤50	5.49	6.47	+17.9	6.64	7.22	+8.7	20.9	11.6
	>50	5.33	6.52	+22.3	6.76	7.55	+11.7	26.8	15.8
	All	5.46	6.47	+18.5	6.69	7.35	+9.9	22.5	13.6
7C	≤50	4.70	§	–	5.63	6.56	+16.5	19.8	–
	>50	§	§	–	5.60	6.31	+12.7	–	–
	All	4.92	§	–	5.61	6.39	+13.9	14.0	–
8SU	≤50	4.84	5.75	+18.8	5.03	5.25	+4.4	3.9	(9.5)
	>50	5.06	5.95	+17.9	5.23	5.73	+9.6	3.4	(3.8)
	All	4.89	5.77	+18.0	5.10	5.37	+5.3	4.3	(7.4)
8C	≤50	4.35	§	–	5.02	5.57	+11.0	15.4	–
	>50	4.15	§	–	5.02	5.83	+16.1	21.0	–
	All	4.26	§	–	5.02	5.79	+15.3	17.8	–

[a] Weighted by sample expansion factors; records with unreported mpg values are dropped.

[§] Fewer than 30 records.

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

TABLE 12 Diesel Versus Gasoline Weighted Average Gallons per Laden TMT by CHCT Class and Usual Operating Area, 1982 and 2002

		Weighted[a] Average GPLTMT				Diesel (Gasoline) GPLTMT Percent Advantage[b]	
	Usual Operating Area (mi)	Gasoline Engine		Diesel Engine			
Truck Class		1982	2002	1982	2002	1982	2002
1	≤50	0.0383	0.0336	§	0.0351	§	(4.5)
	>50	0.0405	0.0482	§	§	§	c
	All	0.0387	0.0380	§	0.0383	§	(0.8)
2	≤50	0.0278	0.0242	0.0210	0.0209	32.4	15.8
	>50	0.0270	0.0235	0.0240	0.0196	12.5	19.9
	All	0.0276	0.0240	0.0224	0.0205	23.2	17.1
3	≤50	0.0227	0.0191	0.0184	0.0160	23.4	19.4
	>50	0.0212	0.0188	0.0185	0.0157	14.6	19.7
	All	0.0224	0.0190	0.0185	0.0159	21.1	19.5
4	≤50	0.0203	0.0158	0.0158	0.0135	28.5	17.0
	>50	0.0202	0.0150	0.0154	0.0131	31.2	14.5
	All	0.0203	0.0159	0.0156	0.0133	30.1	19.5
5	≤50	0.0183	0.0153	0.0142	0.0127	28.9	20.5
	>50	0.0179	0.0155	0.0133	0.0120	34.6	29.2
	All	0.0182	0.0153	0.0138	0.0125	31.9	22.4
6SU	≤50	0.0149	0.0127	0.0121	0.0105	23.1	21.0
	>50	0.0148	0.0133	0.0112	0.0097	32.1	37.1
	All	0.0148	0.0125	0.0117	0.0102	26.5	22.5
6C	≤50	0.0189	§	0.0156	§	21.2	§
	>50	§	§	0.0135	0.0147	§	§
	All	0.0184	§	0.0143	0.0137	28.7	§
7SU	≤50	0.0125	0.0104	0.0102	0.0092	22.5	13.0
	>50	0.0127	0.0100	0.0101	0.0088	24.8	13.6
	All	0.0126	0.0103	0.0101	0.0091	24.8	13.2
7C	≤50	0.0141	§	0.0117	0.0100	20.5	§
	>50	§	§	0.0120	0.0105	§	§
	All	0.0135	§	0.0119	0.0103	13.4	§
8SU	≤50	0.0094	0.0085	0.0071	0.0065	32.4	30.8
	>50	0.0096	0.0072	0.0062	0.0059	54.8	22.0
	All	0.0095	0.0084	0.0067	0.0063	39.7	33.3
8C	≤50	0.0099	§	0.0059	0.0049	67.8	§
	>50	0.0090	§	0.0058	0.0047	55.2	§
	All	0.0095	§	0.0059	0.0047	61.0	§

TABLE 12 (Cont.)

---

[a] Weighted by sample expansion factor; records with unknown mpg and weight information are dropped.

[b] On respective gallon basis, ignoring the difference in energy contents.

§ Fewer than 30 records.

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

The above measurements of diesel engine advantages in mpg and GPLTMT did give an unfair advantage to diesel, however, because of the relative engine weights of the two engines. While other vehicle components and accessory weights are about the same in a given class for both engine types, comparable diesel engines are heavier than gasoline engines for the reasons described below:

> Naturally aspirated diesel engines are heavier than gasoline engines of the same power for two reasons. The first is that it takes a larger displacement diesel engine to produce the same power as a gasoline engine. This is essentially because the diesel must operate at lower engine speeds.[12] Diesel fuel is injected just before ignition, leaving the fuel little time to *find* all the oxygen in the cylinder. [Author notes: It is our observation that technological advances have since resulted in multiple diesel fuel injections during the combustion phase of the diesel engine's operating cycle. Further, diesel engines are now consistently turbocharged to replace their weight disadvantage.] In the gasoline engine, air and fuel are mixed for the entire compression stroke, ensuring complete mixing even at higher engine speeds. The second reason for the greater weight of a diesel engine is it must be stronger to withstand the higher combustion pressures needed for ignition, and the shock loading from the detonation of the ignition mixture. As a result, the reciprocating mass (the piston and connecting rod), and the resultant forces to accelerate and to decelerate these masses, are substantially higher the heavier, the bigger and the stronger the part, and the laws of diminishing returns of component strength, mass of component and inertia — all come into play to create a balance of offsets, of optimal mean power output, weight and durability[13] (also see footnote 14; answers.com undated).

---

[12] Perkins Engine Company Limited, undated, *Engine Genetics*, http://www.perkins.com/cda/components/fullArticle?m=114301&x=7&id=284124. Accessed Dec. 19, 2008.

[13] Perkins Engine Company Limited, undated, *Perkins Engines — Industrial Power Solutions*, http://www.perkins.com/cda/components/fullArticleNoNav?ids=2841248languageID=7, as cited in Associated Press 1982

As a result, the best measure of the energy efficiency of truck cargo movement is GPCTMT, because it is the only one that gives diesel and gasoline engine trucks credit for the cargo payload transported, but not the truck engine and accessories weight. Table 13 provides 2002 GPCTMT estimates for all single-unit commercial truck classes, but for Class 6, 7, and 8 combination trucks (6C, 7C, and 8C), only diesel truck GPCTMT data are reported in the body of the table because there were not at least 30 records of data for gasoline combination trucks in these classes. The table does have a footnote regarding a far larger number of sample records (21) for Class 8C gasoline trucks versus the 3 records and 1 record available for Class 6C and Class 7C gasoline trucks, respectively.[14]

TABLE 13 Diesel Versus Gasoline Weighted Average Gallons per Cargo TMT by CHCT Class and Usual Operating Area, 1982 and 2002

		Weighted[a] Average GPCTMT				Diesel (Gasoline) GPCTMT Percent Advantage[b]	
		Gasoline Engine		Diesel Engine			
Truck Class	Usual Operating Area (mi)	1982	2002	1982	2002	1982	2002
1	≤50	0.1547	0.1719	§	0.1883	§	(9.5)
	>50	0.1580	0.1976	§	§	§	§
	All	0.1553	0.1808	§	0.1875	§	(3.7)
2	≤50	0.0863	0.1010	0.0778	0.0953	10.9	6.0
	>50	0.0885	0.0911	0.0753	0.0765	17.5	19.1
	All	0.0868	0.0984	0.0765	0.0887	13.5	10.9
3	≤50	0.0622	0.0770	0.0709	0.0634	(14.0)	21.5
	>50	0.0610	0.0662	0.0618	0.0588	(1.3)	12.6
	All	0.0619	0.0739	0.0656	0.0616	(6.0)	20.0
4	≤50	0.0493	0.0455	0.0500	0.0426	(1.4)	6.8
	>50	0.0518	0.0412	0.0444	0.0377	16.7	9.3
	All	0.0500	0.0445	0.0475	0.0408	5.3	9.1
5	≤50	0.0414	0.0424	0.0419	0.0366	(1.2)	15.8
	>50	0.0411	0.0428	0.0369	0.0383	11.4	11.7
	All	0.0414	0.0425	0.0395	0.0371	4.8	14.6
6SU	≤50	0.0281	0.0251	0.0286	0.0284	(1.8)	(13.1)
	>50	0.0284	0.0294	0.0256	0.0277	10.9	6.1
	All	0.0282	0.0260	0.0272	0.0282	3.8	(8.5)
6C	≤50	0.0432	§	0.0350	§	23.4	§
	>50	§	§	0.0333	0.0628	§	§
	All	0.0434	§	0.0340	0.0576	27.6	§

---

[14] In Appendix B, Table B-1 lists the number of TIUS/VIUS 1982 and 2002 records used for all of the tabular data presentations and analyses in this report.

TABLE 13 (Cont.)

		Weighted[a] Average GPCTMT				Diesel (Gasoline) GPCTMT Percent Advantage[b]	
		Gasoline Engine		Diesel Engine			
Truck Class	Usual Operating Area (mi)	1982	2002	1982	2002	1982	2002
7SU	≤50	0.0215	0.0186	0.0214	0.0237	0.5	(27.4)
	>50	0.0224	0.0184	0.0211	0.0219	6.2	(19.0)
	All	0.0217	0.0186	0.0213	0.0229	1.9	(23.1)
7C	≤50	0.0278	§	0.0284	0.0340	(2.2)	§
	>50	§	§	0.0379	0.0305	§	§
	All	0.0268	§	0.0344	0.0314	(28.4)	§
8SU	≤50	0.0149	0.0150	0.0122	0.0123	22.1	22.0
	>50	0.0160	0.0112	0.0101	0.0106	58.4	5.7
	All	0.0152	0.146	0.0114	0.0119	33.3	22.7
8C	≤50	0.0168	§	0.0096	0.0084	75.0	§
	>50	0.0141	§	0.0098	0.0082	43.9	§
	All	0.0155	c, §	0.0097	0.0082	59.8	c, §

[a] Weighted by sample expansion factor, records with unknown mpg and weight information are dropped.

[b] On respective gallon basis, ignoring the difference in energy contents.

[c] This table illustrates that probably very large potential fuel savings could result from the use of Class 8 diesel trucks for cargo hauling. TIUS/VIUS data indicate that for 8 C diesel trucks, there were 56 *billion* VMT driven in 2002 versus only 14 million VMT for 8 C gasoline trucks. However, note that the 21 records of 8 C gasoline truck movements had a GPCTMT of 0.0132 versus the 8 C diesel GPCTMT of 0.0082, for a disadvantage of 61.0% more fuel required per TMT, which is comparable to the 1982 8 C gasoline trucks' 59.8% disadvantage. This number of records (21) was below the usual number of records (30) set as the usual standard for data use in this report, which tends to discourage estimating such fuel savings, but the number is far more than the 3 records for all gasoline 6 C trucks and the 1 record for all 7 C gasoline trucks.

§ Fewer than 30 records.

Source: DOC, U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

6.2 COMPARISON OF FACTORS AFFECTING DIESEL VERSUS GASOLINE FUEL USE BY SINGLE-UNIT TRUCKS

For single-unit trucks, the effect of only giving credit for cargo moved per TMT when measuring fuel gallons consumed substantially reduced the advantage of diesel trucks versus gasoline trucks in every class, and the results actually show a gasoline truck GPCTMT advantage in Class 6 and 7 single-unit trucks. However, while much of this decrease in — and (in two classes) total reversal of — diesel fuel efficiency advantages was attributable to using cargo versus laden weight in the fuel-efficiency estimation equation, another very important factor caused the inherent fuel efficiency advantage of diesel engines to be reduced in comparison with gasoline truck engines. Another review of Table 7, presented earlier, shows how 2002 gasoline trucks had an overall 31% cargo per truck advantage in Class 6 and an overall 41% advantage in

Class 7, which greatly contributed to the 9% and 23% GPCTMT advantages of gasoline trucks over diesel trucks in these classes in Table 13. Similar but lesser cargo-weight-carried advantages in Class 4 and 5 gasoline trucks also contributed to reducing the GPCTMT advantages of diesel trucks shown in Table 13 versus the different indicators shown in Tables 11 and 12.

Similarly, the data in Table 10 show how these cargo weights per truck decreased substantially in Class 3–8 single-unit diesel trucks except in Class 4, which had no change. In particular, Class 7 diesel single units, which have a 23% disadvantage in GPCTMT versus gasoline trucks, had the biggest cargo-per-truck decrease between 1982 and 2002 of 16%, versus only a 1% cargo-per-truck decrease for gasoline Class 7 single-unit trucks.

On the other hand, the data in Table 10 indicate that although Class 8 single-unit diesel trucks had a 9% decrease in overall cargo tons per truck, gasoline trucks in the same class had an even greater overall cargo weight decrease of 12%, which helped the diesel trucks have the 32% 2002 cargo weight advantage shown in Table 7. This occurred despite a 22% increase in gasoline truck cargo per truck in the 1982–2002 period in trips of >50 miles versus a 14% cargo weight decrease for diesel trucks making such trips, as found in the source data for Table 10. Nevertheless, data in Table 13 indicate that diesel Class 8 trucks, which, according to the data in Tables 2 and 6, have by far the most 2002 fuel consumed and cargo TMT per truck of all single-unit diesel trucks, have a 2002 GPCTMT advantage of 23% over Class 8 single-unit gasoline trucks (albeit down from 33% in 1982).

Furthermore, data in Table 10 indicate that gasoline trucks also were not exempt from the 1982–2002 trends toward substantially lower amounts of cargo per truck in all medium and heavy truck classes, except for the less than 3% decrease in Class 7. Indeed, gasoline trucks had cargo-tons-per-truck decreases greater than those of diesel trucks in Classes 3–5. These reduced cargo weights in both diesel and gasoline single-unit trucks, in turn, resulted in the estimates shown in Table 14 of substantial and unusually large 1982–2002 improvements in the GPLTMT fuel efficiency of all truck classes. However, the improvements in GPLTMT fuel efficiency, which also probably resulted from technological advances in engines and other truck components, were either substantially reduced or even turned into the unfavorable 1982–2002 trends, indicating increases in GPCTMT due to cargo-per-truck decreases, as shown for various single-unit gasoline and diesel truck classes in Table 15 (see previous footnote 12).

Thus, it is quite likely that virtually all single-unit trucks (except for, perhaps, those in Class 7 with gasoline engines) were negatively affected by the JIT delivery policies discussed above and/or increases in volume per ton of cargo. Of course, because the data presented in Tables 4 and 5 indicate that the number of Class 2–8 diesel single-unit trucks increased by 1,000% in the 1977–2002 period, from 265,000 to 2.9 million, while Class 2–8 gasoline trucks decreased by 50%, from 2.57 to 1.28 million (the numbers given here total 4.18 million, while FHWA's 2003 *Highway Statistics* reports 5.65 million Class 3–8 single-unit trucks in 2002). Thus, the JIT deliveries aggregate impact on fuel use was probably greater on diesel trucks. In fact, the potential for significantly greater impacts on diesel fuel consumption is especially likely, given the huge triple-digit percent advantages in 2002 single-unit diesel versus gasoline TMT per truck and VMT per truck advantages shown in Table 6.

TABLE 14 Changes in Weighted Average Gallons per Laden TMT by CHCT Class, Usual Operating Area, and Gasoline Versus Diesel Engine, 1982–2002

		Percent Change of Weighted[a] Average GPLTMT[b,c]			
		Single Unit		Combination	
		Percent Increase (+) or Decrease (–)		Percent Increase (+) or Decrease (–)	
Truck Class	Usual Operating Area (mi)	Gasoline Engine	Diesel Engine	Gasoline Engine	Diesel Engine
1	≤50	–12.3	§		
	>50	+16.0	§		
	All	–1.8	§		
2	≤50	–12.9	–0.5		
	>50	–130	–18.3		
	All	–13.0	–8.9		
3	≤50	–15.9	–13.0		
	>50	–11.3	–15.1		
	All	–15.2	–14.1		
4	≤50	–22.2	–14.6		
	>50	–25.7	–14.9		
	All	–21.7	–14.7		
5	≤50	–16.4	–10.6		
	>50	–13.4	–9.8		
	All	–15.9	–9.4		
6	≤50	–14.8	–13.2	§	§
	>50	–10.1	–13.4	§	+8.2
	All	–15.5	–12.8	§	–4.2
7	≤50	–16.8	–9.8	§	–14.5
	>50	–21.3	–12.9	§	–12.5
	All	–18.3	–9.9	§	–13.4
8	≤50	–9.6	–8.5	§	–16.9
	>50	–25.0	–4.8	§	–19.0
	All	–11.6	–6.0	§	–20.3

[a] Weighted by sample expansion factor; records with unknown mpg and weight information are dropped.

[b] On respective gallon basis, ignoring the difference in energy contents.

[c] See Table 12 for weighted average GPLTMT base data.

§ Fewer than 30 records.

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

TABLE 15 Changes in Weighted Average Gallons per Cargo TMT by CHCT Class, Usual Operating Area, and Gasoline Versus Diesel Engine, 1982–2002

		Percent Change of Weighted[a] Average GPCTMT[b,c]			
		Single Unit		Combination	
		Percent Increase (+) or Decrease (–)		Percent Increase (+) or Decrease (–)	
Truck Class	Usual Operating Area (mi)	Gasoline Engine	Diesel Engine	Gasoline Engine	Diesel Engine
1	≤50	+11.1	§		
	>50	+25.1	§		
	All	+16.4	§		
2	≤50	+17.0	+22.5		
	>50	+29.4	+1.6		
	All	+13.4	+15.9		
3	≤50	+23.8	–10.6		
	>50	+8.5	–4.9		
	All	+19.4	–6.1		
4	≤50	–7.7	–14.8		
	>50	–20.7	–15.1		
	All	–11.0	–14.1		
5	≤50	+2.4	–12.6		
	>50	+4.1	+3.8		
	All	+2.7	–6.1		
6	≤50	–10.7	–0.7	§	§
	>50	+3.5	+8.2	§	+88.6
	All	–7.8	+3.7	§	+69.4
7	≤50	–13.5	+10.7	§	+19.7
	>50	–18.2	+3.8	§	–19.5
	All	–14.3	+7.5	§	–8.7
8	≤50	+0.7	+0.8	§	–12.5
	>50	–30.0	+5.0	§	–16.3
	All	–3.9	+4.4	§	–15.5

[a] Weighted by sample expansion factor; records with unknown mpg and weight information are dropped.

[b] On respective gallon basis, ignoring the difference in energy contents.

[c] See Table 13 for weighted average GPCTMT base data.

§ Fewer than 30 records.

Source: DOC, U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

6.3 COMPARISON OF FACTORS AFFECTING DIESEL VERSUS GASOLINE FUEL USE BY COMBINATION TRUCKS

The good news for the nation's commercial trucking and overall petroleum fuel use is that Class 8 combination (8C) diesel trucks, by far the primary petroleum users in the industry, have bucked the worsening GPCTMT fuel efficiency trends of single-unit trucks described above. Instead, these Class 8C diesels, shown in Table 2 to have increased their fuel use in the 1977–2002 period by 87% (accounting for 56% of the period's diesel truck fuel use increase [see Table 3]), had the best improvement (15.5%) in GPCTMT of any diesel (or gasoline) truck class and the lowest overall GPCTMT of all truck classes, as shown in Tables 13 and 15. These tables also show how this Class 8C diesel trucks' best GPCTMT of 0.0082 in 2002 was an improvement of 15.5% from its 1982 all-truck-classes best of 0.0097. The next-best 2002 GPCTMT was 0.0119 for Class 8 single-unit diesel trucks, which is a very significant 45% higher. The superior 2002 Class 8 C truck GPCTMT was the rate at which 68% of diesel fuel moved cargo in all truck classes, and about 42% of all diesel plus gasoline fuel was used by all commercial trucking (shown in Table 2). This dominance provides key underlying reasons for the analytical results set forth in the next two sections.

This page intentionally left blank.

7 IMPACTS OF CARGO SHIFTS TO DIESEL CLASS 8C TRUCKS ON REDUCING FUEL CONSUMPTION BY CHCTS, 1982–2002

In this section and the next, the focus is on the how the shift in cargo from light, medium, and heavy gasoline and diesel single-unit CHCTs and other combination CHCTs to Class 8C diesel trucks reduces the overall amount of truck fuel used to transport cargo. Thus, from the 1982 and 2002 TIUS/VIUS surveys the sample and population data are only for trucks carrying ≥200 pounds (i.e., cargo-hauling trucks). As a result of using data for only these CHCTs and employing GPCTMT (the best fuel-use effectiveness measure [see analysis in Section 6.1] in terms of cargo hauling), a reduction of about 21% (see Table 16) was estimated over this period.[15]

The shift of CHCTs away from gasoline and toward diesel (distillate) fuel caused an increase in consumption of highway distillate fuel in a range of 98–137% (EIA 2007; TIUS/VIUS data). This exceeded the rate of growth of real GDP of 94% over the 1982–2002 period (DOC undated). *However*, total growth in fuel gallons used by CHCTs (gasoline and distillate) was estimated to be *only* 46%, which is well below GDP growth and the total TMT increase of 86% for all CHCT classes. Thus, CHCTs contributed significantly to the reduction of the energy intensity of the economy over this period. The FHWA revised its estimates of on-road efficiency of combination trucks in 2003 (FHWA 2004, 2005). After this correction, its estimate of growth in fuel demand by all trucks with 6 tires or more (Class 3–8 single-unit trucks) was 60.5%. For this subset of trucks, our estimate of growth of fuel demand to 2002 for CHCTs was 59.8% (Table 16, Class 3–8), which is almost identical to the FHWA's revised estimates.

Our estimates of the changes in fuel consumption per cargo ton mile for the three FHWA truck categories were −20.9% for Class 1–2 CHCTs (2-axle, 4-tire trucks), +4.5% for Class 3–8 single-unit trucks (2-axle, 6-tire or more trucks), and −17.5% for Class 6–8 combination trucks. Because of the positive mix effects (an increasing share of ton-miles handled by Class 8 combination trucks), our estimate for all of these CHCTs combined was the previously noted −21.4%. Our method of isolating trucks only used to haul cargo led to estimates that the rate of growth in the numbers of trucks dedicated to cargo hauling increased steadily as the trucks categories got heavier (31%, 49%, and 57%, respectively — see Table 16). Similarly, the 2002 shares of total cargo TMT increased significantly as vehicle categories went from lighter to heavier (156 billion TMT or 7% for light, 298 billion TMT or 13% for medium, and 1.82 trillion TMT or 80% for heavy). Because the estimated efficiency in hauling cargo increases considerably when combination trucks move from lighter to heavier, the net system efficiency of the fleet rose accordingly. And, as indicated in Table 4, 97% of all combination trucks are Class 8C diesel trucks. Furthermore, Table 10 shows that diesel trucks in Class 8C were the only trucks to have a net increase in cargo tons per truck between 1982 and 2002 (from 19.9 to 20.6 tons), while most truck classes had double-digit percentage decreases. *Therefore, truck mix shift effects — toward heavier, more efficient trucks — caused the aggregate systemwide percentage reduction (−21.4%) in GPCTMT to exceed the percentage amount for any single class.*

---

[15] In Appendix C, we compare this estimate to a logically comparable measure for passenger vehicles: fuel used per passenger mile of travel. Appendix C and Table C-1 will show the same improvement of approximately 21% in fuel consumption per comparable unit of service as that achieved by CHCTs in the 1982–2002 period.

TABLE 16 Estimated CHCT Attributes by Class Group for Single-Unit and Combination Trucks, 1982 and 2002

FHWA Size Category and GVW Class	Year and Change	Gallons per Cargo Ton Mile (GPCTMT)	Number of Trucks	Gallons of Gasoline and Diesel (10^3)	VMT (10^6 mi)	Cargo TMT (10^6 mi)	Cargo TMT Share in Category (%)	Gallons per Vehicle Mile	Average Miles per Vehicle
Total, all FHWA size categories	1982	0.020212	12,727,052	24,674,926	196,308	1,220,797	100	0.12569	15,424
	2002	0.015878	17,271,142	36,082,979	339,305	2,272,454	100	0.10634	19,646
	% change	**−21.4**	35.7	46.2	72.8	86.1	0	−15.4	27.4
Total, GVW Class 3–8	1982	0.012383	3,045,400	13,929,829	73,901	1,124,960	92	0.18849	24,266
	2002	0.010519	4,610,211	22,266,627	138,377	2,116,720	93	0.16091	30,015
	% change	−15.1	51.4	59.8	87.2	88.2	1	−14.6	23.7
Combination	1982	0.01029	864,637	9,499,983	47,220	923,049	76	0.20118	54,613
	2002	0.00849	1,356,847	15,434,420	88,757	1,818,747	80	0.17390	65,414
	% change	−17.5	56.9	62.5	88.0	97.0	4	−13.6	19.8
2-axle, 6-tire or more single unit	1982	0.02194	2,180,763	4,429,846	26,681	201,911	17	0.16603	12,235
	2002	0.02293	3,253,364	6,832,207	49,620	297,973	13	0.13769	15,252
	% change	4.5	49	54	86	48	−4	−17.1	24.7
2-axle, 4-tire single unit	1982	0.11212	9,681,652	10,745,097	122,407	95,837	8	0.08778	12,643
	2002	0.08872	12,660,931	13,816,352	200,928	155,734	7	0.06876	15,870
	% change	−20.9	31	29	64	62.5	−1	−21.7	25.5

Source: DOC, U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

8 OTHER INDICATORS OF CHCT EFFICIENCY IMPROVEMENTS

The aggregate efficiency of the commercial trucking system, in terms of ton-miles of cargo moved per unit of fuel, improved considerably as more cargo tons were moved by Class 8 combination diesel trucks (Table 10), with the best GPCTMT on long trips in the period 1982–2002 (Tables 13, 15, and 17). The movement of cargo from smaller classes of trucks to Class 8 combination diesel trucks is also indicated by the small 60 billion and 96 billion increases in TMT for Class 1–2 and Class 3–8 single-unit trucks, respectively, in 1982–2002, versus the 896 billion increase in TMT for combination trucks (Table 16).

A 481% increase in single-unit Class 1–8 diesel fuel use during 1977–2002 versus a 1,047% increase in the number of trucks was shown in Tables 2 and 4, respectively. Our TIUS/VIUS analysis indicates that this high truck-number increase was due to two reinforcing effects: a decrease in cargo per diesel truck and a decrease in miles driven per diesel truck. The 1982–2002 TIUS/VIUS data indicate that the change in cargo TMT per single-unit diesel truck ranged from –45% for Class 7 to –13% for Class 4 (Table 17). Only Class 6 and 8 diesel combination trucks increased cargo TMT per truck. In addition, for Class 3–8 single-unit trucks, the average miles driven per diesel truck dropped 19% (Table 18), even though the average for both gasoline and diesel trucks combined rose significantly — by 25% in our TIUS/VIUS CHCT estimates (Table 16) and 52% in FHWA all truck estimates (Table 9).

Table 18 shows that for Class 8C diesel trucks in 1982–2002, those usually operating >50 miles had increased annual VMT, by about 9,000 miles per truck, from 72,773 to 81,860 miles (+12.5%), whereas for those operating ≤50 miles, annual VMT per truck decreased by about 3,000 miles, from 31,212 to 28,556 (−8.5%). Also, trucks operating >50 miles increased their share of overall Class 8C VMT from 85.9% to 87.2% (+1.6%), versus those operating ≤50 miles, the share of which dropped from 14.1% to 12.8% (−9.2%). These increases in VMT per truck and VMT shares of the long-haul trucks, in combination with the increased tons (Table 10), resulted in the increase of 15.8% or 235,000 annual cargo TMT per truck for Class 8C diesel trucks operating >50 miles versus the decrease of 6% or 38,000 annual cargo TMT per truck for Class 8C trucks operating ≤50 miles (Tables 17, 18). Most of the cargo shifted from single-unit Class 3–8 trucks into Class 8C diesel trucks traveling >50 miles, because Class 8C trucks operating ≤50 miles did not gain; instead, they lost 5.5% of their annual cargo TMT share. Table 18 also shows dramatic decreases of 51% and 59% in the weighted average cargo TMT for Class 3–8 single-unit diesel trucks for trips of ≤50 and >50 miles, respectively.

A study conducted at two universities (see Section 4.1) that used TIUS/VIUS data found that long-haul trips (>200 miles) by Class 7 and 8 trucks increased by 340% in the 1977–2002 period, while local trips (≤50 miles) by these trucks increased by only 42% *(*Burks et al. 2004b*)*. Burks et al. also wrote an article based on VIUS data that described the increasing intensive (average annual VMT per truck) use of Class 7 and 8 trucks combined by both truckload and less-than-truckload carriers during the 1990s (Burks et al. 2004a).

TABLE 17 Cargo TMT per CHCT for Diesel Versus Gasoline Engines, 1982–2002

Truck Class	Usual Operating Area (mi)	Cargo TMT/Truck Gasoline Engine		Percent Increase (+) or Decrease (–)	Cargo TMT/Truck Diesel Engine		Percent Increase (+) or Decrease (–)
		1982	2002	1982–2002	1982	2002	1982–2002
1	≤50	5,669	4,677	–17.4	§	5,952	–
	>50	10,622	9,597	–9.6	§	§	–
	All	6,203	5,690	–8.3	§	7,686	–
2	≤50	14,095	10,321	–26.8	19,455	13,139	–32.5
	>50	21,366	19,184	–10.2	46,847	23,939	–48.9
	All	15,183	11,679	–23.1	27,524	15,594	–43.3
3	≤50	19,061	14,006	–38.7	23,734	24,606	+3.7
	>50	32,880	25,622	–22.1	56,438	33,779	–39.9
	All	20,831	16,130	–22.6	35,934	27,419	–23.7
4	≤50	25,649	20,048	–21.8	48,277	45,326	–6.1
	>50	46,090	37,900	–17.8	96,310	78,724	–18.3
	All	28,969	22,342	–22.9	62,127	54,081	–13.0
5	≤50	31,327	24,921	–20.4	56,605	51,572	–8.9
	>50	63,900	42,355	–33.7	105,105	59,172	–43.7
	All	35,979	28,881	–19.8	72,480	53,703	–25.9
6SU	≤50	42,571	27,561	–35.3	90,933	66,594	–26.8
	>50	92,667	49,813	–46.2	164,454	113,895	–30.7
	All	48,342	30,095	–37.7	115,519	79,231	–31.4
6C	≤50	53,527	§	–	102,720	§	–
	>50	47,832	§	–	229,540	244,447	+6.5
	All	52,654	§	–	152,752	179,539	+17.5
7SU	≤50	70,413	29,282	–58.4	135,481	74,091	–45.3
	>50	153,154	73,737	–51.9	254,899	143,074	–43.9
	All	79,284	32,292	–59.3	169,194	92,737	–45.2
7C	≤50	93,615	§	–	121,314	73,681	–39.3
	>50	100,355	§	–	279,000	301,396	+8.0
	All	94,791	§	–	188,987	163,062	–13.7
8SU	≤50	121,356	31,726	–73.9	345,544	273,529	–20.8
	>50	226,056	47,312	–79.1	797,984	441,538	–44.7
	All	134,567	32,751	–75.7	433,520	307,646	–29.0
8C	≤50	153,165	§	–	648,557	610,716	–5.8
	>50	439,227	§	–	1,483,421	1,718,506	+15.8
	All	220,911	§	–	1,251,920	1,390,705	+11.1

§ Fewer than 30 records.

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

TABLE 18 Diesel Class 8C Versus Class 3–8 Single-Unit CHCTs by Usual Operating Area: Average VMT and TMT per Truck and Shares of Total VMT and Cargo TMT, 1982–2002

	Class 3–8 Single-Unit Diesel Trucks			Class 8C Combination Diesel Trucks		
VMT and Cargo TMT by Usual Operating Areas	1982	2002	Percent Change	1982	2002	Percent Change
Average annual VMT/truck						
All trucks	23,498	19,042	−19.0	61,248	66,087	+7.9
Operating ≤50 miles	19,524	16,074	−17.7	31,212	28,556	−8.5
Operating >50 miles	35,852	26,137	−27.1	72,773	81,860	+12.5
Percent of total annual VMT						
Operating ≤50 miles	62.9	85.0	+35.1	14.1	12.8	−9.2
Operating >50 miles	37.1	15.0	−59.6	85.9	87.2	+1.6
Average annual cargo TMT/truck						
Operating ≤50 miles	272,087	132,689	−51.2	648,558	610,716[a]	−5.8
Operating >50 miles	459,709	188,599	−59.0	1,483,421	1,718,506[a]	+15.8
Percent of annual cargo TMT						
Operating ≤50 miles	63.0	62.3	−1.1	14.6	13.8	−5.5
Operating >50 miles	37.0	37.7	+1.9	85.4	86.2	+0.9

[a] Besides greater VMT and TMT per truck, in 2002, Class 8C trucks traveling >50 miles had 20.8 cargo TMT/truck; Class 8C trucks traveling ≤50 miles had a lower amount, 20.13 cargo TMT/truck.

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

In contrast for our disaggregate estimates by fuel type, we estimate in Table 18 that only Class 8C diesel CHCTs operating >50 miles significantly increased VMT per truck in 1982–2002, and the average VMT for short-distance Class 8C diesel trucks slightly decreased in that period.

Our results show the dramatic effect on annual miles per average truck accomplished by the shift from gasoline to diesel. Despite declines in annual miles per single-unit truck by both fuel types (Table 19), there was a significant *increase* in *overall* miles per single-unit truck (Table 16). This was because diesels are consistently driven far more miles per year than gasoline trucks (Table 19), and the dramatic shift shown in Figure 2 led to the increase estimated in Table 16.

TABLE 19 Changes in Weighted Average VMT of Single-Unit Class 3–8 CHCTs by Usual Operating Area and Gasoline Versus Diesel Engine, 1982–2002

Truck Class	Usual Operating Area (mi)	Gasoline Engine VMT		Percent Increase (+) or Decrease (–)	Diesel Engine VMT		Percent Increase (+) or Decrease (–)
		1982	2002	1982–2002	1982	2002	1982–2002
3	≤50	8,568	9,387	+9.6	14,674	15,790	+7.6
	>50	15,218	15,366	+1.0	30,211	20,737	–31.4
	All	9,420	10,480	+11.3	20,470	17,307	–15.5
4	≤50	8,070	7,516	–7.8	19,745	18,611	–5.7
	>50	15,320	13,774	–10.1	36,039	29,508	–18.1
	All	9,247	8,320	–10.0	24,443	21,468	–12.2
5	≤50	7,957	7,811	–1.8	18,666	16,788	–10.1
	>50	16,499	13,176	–16.5	32,339	21,051	–34.9
	All	9,197	9,030	–1.8	23,142	17,983	–22.3
6SU	≤50	7,125	4,870	–31.6	18,764	15,798	–15.9
	>50	15,481	10,460	–32.4	32,492	27,895	–14.1
	All	8,087	5,507	–31.9	23,354	19,030	–18.5
7SU	≤50	8,325	3,519	–57.7	19,247	12,673	–34.2
	>50	18,329	8,861	–51.7	36,314	23,622	–35.0
	All	9,398	3,881	–58.7	24,068	15,632	–35.1
8SU	≤50	8,763	2,735	–68.8	21,121	17,692	–16.2
	>50	18,363	3,155	–82.8	42,266	27,168	–35.7
	All	9,974	2,762	–72.3	25,232	19,616	–24.2

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006

9 IMPACTS OF GROWING DIESEL DOMINANCE IN COMMERCIAL TRUCKING ON NATIONAL PETROLEUM USE

9.1 GROWING DISTILLATE AND HIGHWAY DIESEL FUEL SHARES OF NATIONAL PETROLEUM CONSUMPTION

Since 1986, the rate at which highway diesel fuel was used was not only the fastest of any distillate made from petroleum but was also at a far faster rate than for gasoline, as was shown in Figure 1. In addition, EIA data in Figure 4 illustrate how since 1987, highway diesel truck distillate use grew by 88%, from 18.2 billion gallons (40% of national distillate use) to 34.3 billion gallons (59% of national distillate use). This increase occurred while other nonhighway uses of distillate declined by 14% (EIA 2004).

A similar dramatic national trend in the total transportation sector use of distillate versus gasoline occurred in the 1977–2002 period, which the above paragraph and Figure 3 indicate was primarily due to increases in diesel use on highways. Table 20, for example, shows that the annual use of distillates by the transportation sector grew by 117% (or about 500 million barrels) during this period, while the annual use of gasoline grew by only 23% (or about 600 million barrels), from a much larger base. As a result, the table shows that distillate's share of the combined distillate-gasoline use grew from 14% of the total to 23%, while gasoline's share decreased from 86% to 77% (EIA 2006). Similarly, Table 21 shows that the growth in the use of distillates was relatively steady, increasing by 45% in the 1977–1991 period and by 50% in the 1991–2003 period. On the other hand, the use of gasoline grew by less than 1% in 1977–1991 and then by a much larger 23% in 1991–2003, when virtually all growth in gasoline use during 1977–2003 occurred (EIA 2006). Table 21 divides this 1977–2003 period into these two parts to provide a basis for indicating that the growth spurt in national highway motor gasoline use was not due to increases in gasoline commercial truck use, but rather due to the increase in the number of personal-use sports utility vehicles (SUVs) and other light-duty trucks that began in 1992. These Class 1 and 2 gasoline vehicles grew from 4.06 million units sold, or 33% of passenger car and light truck sales in 1992, to 7.51 million vehicles units solid in 2002, or 48% of passenger car and light truck sales (Bureau of Transportation Statistics 2004). As described in *Harper's Magazine,* after several new SUVs were launched in 1990, Operation Desert Storm moved "all-terrain vehicles into prime time" and convinced "main stream America that the fuel crisis was finally over" and to "stop worrying and love the SUV" (Roberts 2001) This phenomenon, as shown in Table 21, significantly slowed the steady growth in the share of highway diesel distillates in overall petroleum use, which was shown in Tables 2 and 20 and Figure 4 to have grown significantly since 1977 and 1986, respectively.

9.2 FASTEST GROWTH RATE FOR TRANSPORTATION DISTILLATE, 1977-2002

Table 22 shows that transportation petroleum use grew by 35% in the 1977–2002 period, versus 7% for overall national petroleum use, and that the increase of about 1.3 billion barrels in per annum transportation use was significantly higher than the increase in total national

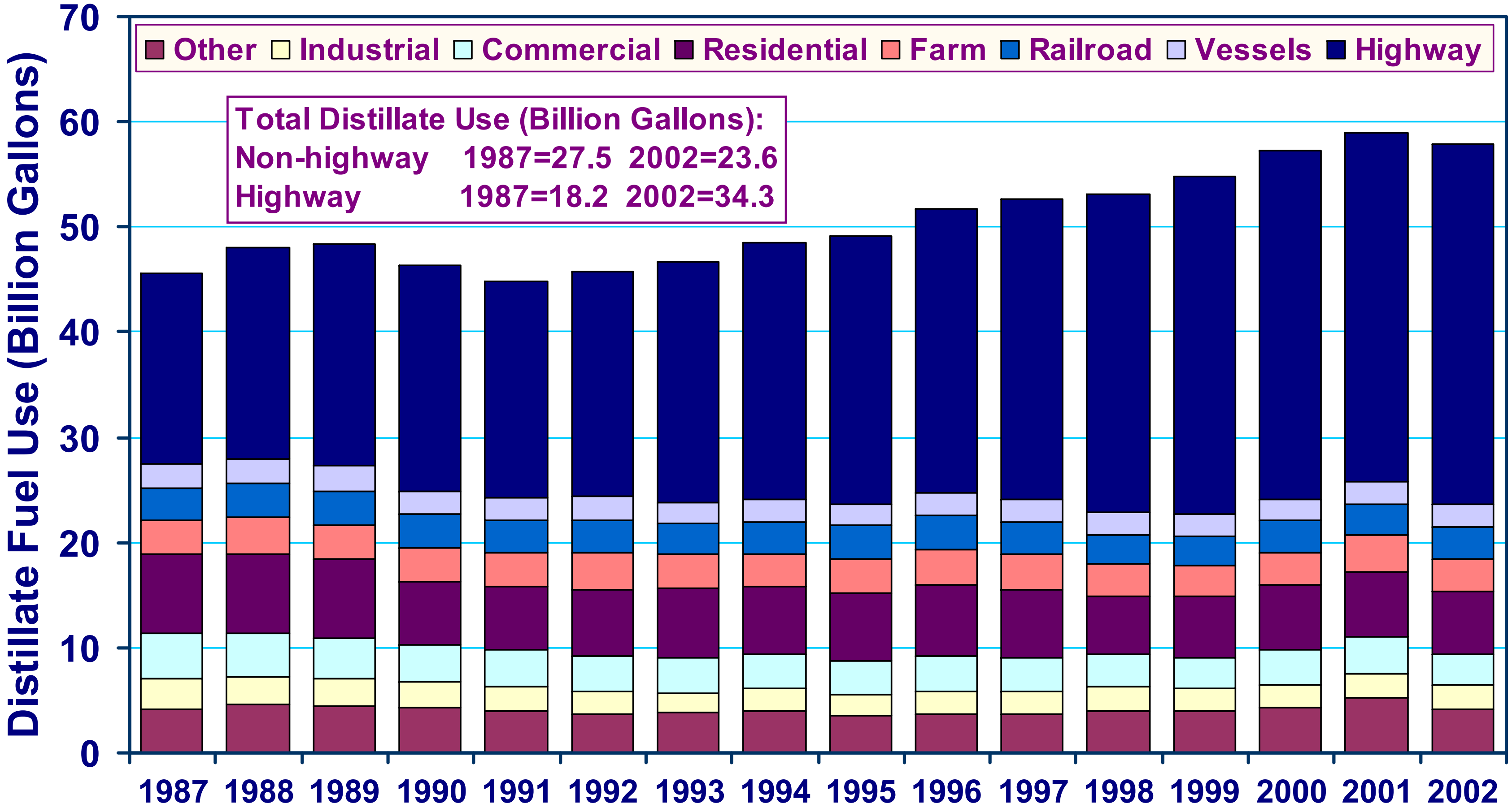


FIGURE 4 Distillate Uses by Highway and Nonhighway Transport Category, 1987–2002 (Source: EIA 2004)

TABLE 20 Growth in Use and Shares of U.S. Distillate Versus Motor Gasoline, 1977–2002

	Consumption and Shares per Year and Growth					
Petroleum Type	1977 (10^6 bbl)	% Share	2002 (10^6 bbl)	% Share	Increase (10^6 bbl)	% Increase
Distillate	427	14.3	926	22.7	499	117
Motor gasoline	2,563	85.7	3,161	77.3	598	23.4

Source: EIA (2006)

TABLE 21 Changes in Growth in Use of U.S. Distillate and Motor Gasoline, 1977, 1991, and 2002

	Consumption per Year and Growth					
					% Change from:	
Petroleum Type	1977 (10^6 bbl)	1991 (10^6 bbl)	% Change	2002 (10^6 bbl)	1977	1991
Distillate	427.2	618.1	44.7	926	117	49.8
Motor gasoline	2,563	2,570	0.3	3,161	23.4	23.0

Source: EIA (2006)

consumption of about 0.5 billion barrels (EIA 2006). This indicates that overall national use of petroleum for nontransportation applications actually declined during this period, while the national use of petroleum for transportation applications more than doubled the net national increase. In addition, transportation's share of overall national petroleum use grew from 53% to 67% during this period.

Table 22 also indicates that the use of distillates for transportation (by highway, rail, and marine) constituted the fastest-growing element of national petroleum use. Here (as in Table 20), the use of distillates is shown to have grown almost as much in absolute terms as the use of motor gasoline (about 500 million versus 600 million barrels). Moreover, during 1977–2002, distillate's share of U.S. petroleum use doubled (from 6.4% to 12.8%), and with the fastest rate of share increase (102%), far outstripped the corresponding value for gasoline (15%) and transportation's share of overall petroleum use (26%).

TABLE 22 Changes in Use and Shares of Total Petroleum Products in U.S. Transportation Sector, 1977–2002[a]

	1977		2002		1977–2002			
Petroleum Type	Consumption (10^6 bbl)	Share of U.S. Petroleum Use (%)	Consumption (10^6 bbl)	Share of U.S. Petroleum Use (%)	Total Consumption Change (10^6 bbl)	Change in Consumption (%)	Change in Share (%)	Rate of Change in Share (%)
Distillate	427	6.4	926	12.8	499	116.7	6.5	102.1
Motor gasoline	2,563	38.1	3,161	43.8	598	23.4	5.7	15.0
Jet fuel and aviation gasoline	387	5.8	596	8.3	209	54.0	2.5	43.6
Liquid petroleum gases and lubricants	41	0.6	31	0.4	–10	–26.2	–0.2	–31.2
Residual fuel oil	145	2.1	108	1.5	–37	–25.2	–0.7	–30.5
Total transportation use	3,563	53.0	4,821	66.8	1,258	35.3	13.9	26.2
Total U.S. petroleum end use	6,727		7,213			7.2		

[a] Some columns do not add because of rounding. Change in use of petroleum in 1977–2002 period: transportation use was +1,258 million bbl, U.S. total end use was +485 million bbl, nontransportation end use was −773 million bbl.

Source: EIA (2006)

9.3 DOUBLING OF HIGHWAY DISTILLATE USE, 1982–2002

A more detailed breakdown of additional EIA data on end-use distillate consumption was used to estimate 1982–2002 growth in highway distillate use (EIA 2007), providing confirmation of TIUS/VIUS survey data. Because EIA's highway distillate use data began in 1984, we used FHWA special fuel-use data to adjust EIA's 1984 data on distillate fuels to estimate highway diesel use in 1982. The analysis estimated that highway distillate use grew from 14.5 billion gallons in 1982 (EIA 2007, DOT undated) to 34.3 billion gallons in 2002 (EIA 2007), which is a 137% increase. Alternative estimates constructed from 1982–2002 TIUSs and VIUS (TIUS/VIUS data) indicate that the growth in highway distillate was 98%.

Either way, the use of highway distillate approximately doubled (or more) during the period. On the other hand, EIA's end-use sectors fuel consumption data were used to estimate that nonhighway uses of distillate dropped from 26.5 billion gallons in 1982 (EIA 2006, 2007) to 23.6 billion gallons in 2002 as reported by Perkins Engine Company Limited[16] (−11%). (The terms "highway distillate" and "highway diesel fuel" are used interchangeably in this report, consistent with the convention of the particular source being used.)

In summary, the 1982–2002 data indicate that the use of highway diesel grew by 98–137%, which is far faster than the increase in all highway gasoline of 35% (EIA 2007; TIUS/VIUS data). Obviously, the fastest-growing category of refined petroleum products used in the United States during 1982–2002 was highway diesel.

9.4 SIGNIFICANT MITIGATION OF THE IMPACT OF HIGHWAY TRANSPORTATION'S INCREASING SHARE OF NATIONAL PETROLEUM USE CAUSED BY CLASS 8C DIESEL CHCTS

Table 23 indicates there was a complete role reversal between diesel and gasoline CHCTs in the 1977–2002 period. Diesel trucks went from a 41% share of total petroleum consumed to a 62% share. Gasoline trucks' consumption went from a 59% to a 38% share. Table 10 shows how there was a major shift of cargo into Class 8C diesel trucks, which had the only increase in cargo tons per truck. Virtually all other diesel and gasoline truck classes had double-digit decreases in cargo tons per truck. And Table 17 shows how Class 8C diesels had a 16% increase in cargo TMT per truck, while virtually all other diesel and gasoline trucks classes had double-digit decreases in cargo TMT per truck. Further, Table 18 shows how most of this shifted cargo went on the most fuel-efficient trips (>50 miles), and Table 15 indicates that the fuel efficiency of Class 8C diesels increased 16% in 1982–2002, and that their GPCTMT of 0.0082 was significantly better than the next-best CHCT GPCTMT (0.119 for Class 8 SU diesels), which was 45% higher. *Finally, Table 16 indicates that the switch of CHCTs from gasoline to diesel fuel, combined with the shift of cargo TMT into Class 8C diesel trucks, resulted in an 86% increase in cargo TMT moved but only a 46% increase in total petroleum consumed, thanks to an estimated 21% reduction in fuel use per cargo ton-mile. This 21% GPCTMT reduction did*

---

[16] Perkins Engine Company Limited, undated, *Engine Genetics*, http://www.perkins.com/cda/components/fullArticle?m=114301&x=7&id=284124. Accessed Dec. 19, 2008.

much to mitigate the national petroleum use impact from the cargo TMT increase achieved by the trucking industry during this period.

TABLE 23 Estimated Gasoline Versus Diesel Shares of All U.S. Commercial Trucking Fuel Use, 1977 and 2002

Commercial Trucking Fuel Use Type	Estimated 1977 Consumption (10^6 gal)	Percent Share	Estimated 2002 Consumption (10^6 gal)	Percent Share
Gasoline	13,777	59.2	13,755	38.1
Diesel	9,510	40.8	22,328	61.9
Total	23,287	100.0	36,083	100.0

Source: U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006; also see Table 2

10 IMPORTANT REGULATORY CHANGE

Our review of the data established that the 21% systemwide reduction in average gallons consumed per cargo ton-mile resulted from two key shifts. The first, which we emphasized, was the shift of powertrain technology from gasoline to diesel. However, the intuition that this simple shift would always provide benefits was contradicted by the field data in TIUS and VIUS. Across all medium-duty Class 3–7 CHCTs, we found that there was an increase in gallons consumed per cargo ton-mile in the 1982–2002 period (Table 16), even though the diesel powertrain was consistently technically more efficient than the gasoline powertrain in moving mass (Table 12). There were two key reasons that the technical efficiency did not translate into "on-road" cargo hauling efficiency. First, a truck with a diesel powertrain was heavier than one with a gasoline powertrain, which reduced cargo-carrying capability for a given weight class. Second, there was a trend toward smaller loads in these medium-duty trucks, even when the engine type was held constant (Table 10).

The overall data demonstrated that for both diesel and gasoline engines, the heavier the class of truck was (Table 13), and the heavier the load carried in that class was (Table 10), the lower was the amount of fuel consumed per cargo ton-mile of travel (Table 13). Thus, shifting the percentage of cargo carried from medium-duty trucks (Class 3–7) to the heaviest trucks (Class 8) improved the average systemwide efficiency.

Furthermore, for Class 8 single-unit and combination trucks in 1982, a switch from gasoline to diesel powertrains meant a significant increase in the average load carried. This switch was in the opposite direction to the change in every other class of truck. Thus, since bigger (heavier) was better with respect to fuel consumed per cargo ton-mile, the switch to Class 8 diesels had a benefit beyond that conferred by the inherent efficiency of the diesel powertrain. For the Class 8 combination truck, one more advantage of size was added beyond that realized by Class 8 single-unit trucks in 1982–2002. Not only were Class 8 combination trucks the most efficient in both 1982 and 2002, they also increased their average (within class and type) load carried over this time period, unique among all truck classes and types (Table 10). So, not only did the Class 8 combination truck have a clear advantage in fuel consumption per cargo ton-mile at the outset of the study period, it was also the only class able to expand that advantage over the study period by means of increased cargo loading.

Why was this possible? A key piece of legislation was passed at the outset of the study period (see Section 5.3). It required and enabled the interstate highway system to consistently allow larger Class 8 combination trucks designed to carry heavier cargo loads. In late 1982, the gasoline tax was increased from 4 to 9 cents per gallon to pay for improvements to the roadbeds and bridges of the interstate highway system and make them compatible with heavier maximum combination truck loads nationwide. In addition to this gasoline tax increase, the annual user fees charged to trucks were raised from $240 to a maximum of $1,600 per year in 1984 and then increased to $1,900 per year in 1988.[17]

---

[17] Associated Press, 1982, "Bigger Heavier Trucks OK'd as U.S. Hikes Taxes," *Chicago Tribune*, Section 4, p. 8, Dec. 27.

Weight ceilings that had limited the maximum weight in Arkansas, Missouri, and Illinois relative to typical states were raised to 80,000 pounds. Fourteen states were also required to allow longer double trailers. (This requirement was relatively unimportant, on the basis of our VIUS investigations of cargo share carried by tandem trailers.) Also in 1982, 46 states were required to increase their truck width standards to 102 inches, which increased the volume of freight that could be carried in Class 8 combination trucks.

An argument in favor of the legislation by trucking association president Bennet J. Whitlock, Jr., was that "uniform national standards would enhance productivity and save fuel by eliminating barriers such as the one on heavy trucks in the Midwest" (see footnote 16). Our investigation over a quarter of a century later supported the long-run validity of this argument.

The gasoline tax caused passenger vehicle owners to pay for the improvements to the infrastructure demanded by the trucking industry. The higher truck user fees originally sought by the Reagan Administration were reduced by using the gasoline tax increase to raise the needed funds for infrastructure improvement. In effect, all highway users were required to pay for the upgrades to the interstate highway infrastructure.

11 SUMMARY AND CONCLUSIONS

Because highway diesel fuel had the fastest growth rate (135%, Table 23) of all national petroleum fuels, and because the dominant user of distillate is truck transport, the major reduction in gasoline use and GPCTMT by the CHCT fleet in 1982–2002 is important. As described in the last subsection, most of this GPCTMT reduction was due to cargo shifts from single-unit gasoline and diesel Class 3–8 trucks to the most efficient Class 8 combination diesel trucks traveling >50 miles (Tables 10, 15, 17, and 18). These trucks had by far the best fuel efficiency of 0.0082 GPCTMT, which improved by 16% in the 1982–2002 period (Table 15). A key factor contributing to these trends was the prior construction and 1982 and beyond upgrading of the 42,000-mile Interstate highway system, which was specifically constructed to foster the long-distance, steady-speed trips conducive to Class 8C diesel truck fuel efficiency. Also, demographic population shifts from densely populated central cities to dispersed suburbs, plus increased international trade through the nation's coastal seaports, required more long-distance cargo trips, which were enabled by these highways.

The shift of cargoes from less-efficient, smaller trucks to the largest ones helped achieve the even larger improvement in GPCTMT of about 21% in systemwide CHCT (Table 16).[18] In addition, the basic engineering design and performance (especially durability) advantages of diesel engines over gasoline engines played a major role in the huge shift of Class 3–8 gasoline-powered single-unit trucks in 1977 to diesel trucks in those classes, which then became totally dominant in 2002 (Tables 4 and 5). This shift created substantial opportunities for the reduction in fuel use in these smaller trucks. However, the potential fuel savings did not occur to the extent possible because of reductions in cargo weights per truck in these classes (Table 7). The reduction in cargo weight per truck diminished the contribution of these trucks to the overall CHCT fleet reductions in GPCTMT achieved primarily by Class 8 combination diesel trucks (Tables 13, 15, and 16). The heavier engines of all diesel trucks also reduced their cargo hauling fuel savings.

The expected continuing dominance of diesel CHCTs (especially Class 8C diesels) in the trucking industry — and the obvious favorable impact of these trucks on reducing transportation fuel consumption — provide strong justification for national energy and environmental policies that support federal research on ways of further improving the fuel efficiency and durability of diesel truck powertrains while reducing their environmental impacts. One question raised by our research is whether the apparent long-run benefits of the system-efficiency–enhancing legislation of 1982 have been largely exhausted. Does the interstate highway infrastructure require another adequately funded upgrade, and should the size and weight limits of trucks be raised again?

---

[18] FHWA data discussed and presented in Appendix C and Table C-1 indicate that this estimated 21% decrease in CHCT fuel use was comparable to the estimated 21% decrease in fuel use (for passenger miles traveled) achieved byn the passenger vehicle fleet during the same period.

In addition, recent trends not covered by our research through 2002 suggest that all commercial truck powertrains (not just diesel powertrains) warrant additional federal research on ways of improving their fuel efficiency and durability while reducing their environmental impacts. These recent trends and their research implications are discussed in the next section.

12 SUGGESTED FURTHER RESEARCH

One reason for further improving the fuel efficiency and durability of all commercial truck powertrains while reducing their environmental impacts is that recent trends have gone against the diesel engine. In the last decade, regulations have been imposed to reduce emissions of particulates and nitrogen oxides from diesel engines. One advantage of diesel engines in the 1977–2002 period was that they had less strict emission regulations than gasoline engines. This advantage is being eliminated with requirements to install sophisticated, costly aftertreatment equipment on diesel powertrains and to carry out much more "severe" refining of diesel fuels to remove sulfur. The result has been increases in the cost of both the diesel powertrain and the fuel that it uses. Accordingly, the truck gasoline engine —perhaps with the help of hybridization — may slow the rate of expansion of the share of the diesel powertrain.

With respect to durability, our research implies that the advantage of the diesel over the gasoline engine has been formidable. This advantage will probably continue, even when aftertreatment equipment is added to diesel engines, but the gap is likely to narrow.

This study focuses on CHCTs. In part, this focus was a product of the nature of the surveys on which we relied. For purposes of estimating vehicle fuel consumption, we found that the quality of the data for trucks that reported that they carried cargo was vastly superior to the quality of the data for trucks that did not report that they carried cargo. The resulting logical focus on CHCTs unfortunately neglected the fuel consumption of non-cargo-hauling commercial vehicles. Further research designed to delineate the behavior and fuel consumption of non-cargo-hauling commercial vehicles is desirable. Commercial vehicles (i.e., the commercial use of passenger cars) should also be studied. The TIUS and VIUS surveys completely ignored commercial use of passenger vehicles. In effect, they were designed to address trucks as physical vehicles, not the kind of service they provided. So-called light trucks evolved dramatically over the life of these surveys, so that they (including SUVs and minivans, which did not exist when the original TIUS was designed) were used as passenger vehicles far more often than pickup trucks. Pickup trucks were the only light-duty vehicle legally designated as trucks when these surveys were originally designed. The notion that a light-duty "truck" was predominantly a commercial vehicle became fiction over the period that these surveys existed. In addition, the use of passenger cars for commercial purposes was completely ignored.

We observed that when a purchaser chooses a diesel engine over a gasoline engine, the weight of the powertrain and truck is increased. Within a specific class of truck capable of traveling on roads and highways with specific weight limits, this means reduced cargo capacity. We observed that in the single-unit truck, there were reductions in the average cargo load carried. These reductions went beyond the reduction forced on a truck owner when switching from a gasoline to diesel powertrain. Even when the powertrain type was held constant, we saw a reduction in the average load carried by single-unit trucks. What this trend implies is that there is "headroom" in single-unit trucks for the increased powertrain mass and/or volume that improves operating efficiency and/or durability. Over the period of study, this meant that there was room (or powertrain mass increase possibilities on routes traversed) for switching to a diesel powertrain. Now other options are emerging as possible competitors and/or complements to the diesel powertrain: the hybrid powertrain, the natural gas engine, or possibly both.[19] Gasoline, diesel, and natural gas powertrains can be "hybridized." In each case, there will be an increase in the powertrain mass and volume required to achieve efficiency benefits.

A second important trend that we identified was the increasing specialization of single-unit and combination trucks with respect to the length of a usual trip. The share of usual trips of ≤50 miles per day rose for single-unit trucks and declined for combination trucks. This means that the number of stops per mile of travel (a factor that reduces the speed and daily distance driven) for single-unit trucks increased, while it dropped for combination trucks. Hybridization of a gasoline powertrain provides greater fuel savings per hour of operation than does hybridization of a diesel in congested stop-and-go driving. Switching from a gasoline powertrain to a properly hybridized gasoline powertrain can eliminate engine operation when the vehicle is stopped, while switching to a diesel powertrain alone cannot.

Finally, the axle configuration of single-unit trucks is more conducive to obtaining benefits from hybridization than is the axle configuration of combination trucks and trailers. A higher percentage of vehicle load on driven axles is found in single-unit trucks than in combination trucks and trailer sets. This creates a greater opportunity for regenerative braking in single-unit trucks, a positive energy-saving feature of hybrid powertrains.

In summary, with respect to future research, it appears that the study of non-cargo-hauling and ≤200-pound cargo-hauling commercial vehicles is also desirable. These vehicles will almost exclusively have "straight" (single-unit) powertrains and — compared to CHCTs — will be disproportionately used for urban deliveries of cargo weighing ≤200 pounds and for service calls involving slow average speeds and a high percentage of stops. Many of them may be passenger cars, not just trucks. In such applications, the relative competitiveness of the hybrid powertrain is at its greatest. This emerging technology will add a fuel-use-reducing alternative in urban commercial vehicle applications. The size and nature of this potential market needs to be better understood. Public policy to promote fuel efficiency will be fundamentally different for commercial vehicles than for personal-use vehicles. Accordingly, the nature of the commercial non-cargo-hauling vehicle market needs to be well defined if good oil-saving research and development strategies and public policies are to be implemented for this segment of the on-highway market.

Finally, natural gas fuels also deserve evaluation. Even though it may not reduce energy use, switching to natural gas may reduce lifetime operating cost and greenhouse gases in some commercial truck uses. Where natural gas is concerned, energy storage per unit volume is a concern. Unlike hybridization, where a small amount of added energy storage volume (a battery)

---

[19] Here, a hybrid powertrain is one that — in addition to an engine — uses one or more electric machines and an electricity storage device, such as a battery or ultra-capacitor, to temporarily store electricity for use to power the vehicle and its accessories. Electric machines are more commonly known as motors or generators. Electric machines are capable of operating both as generators (during braking) and motors (during acceleration and occasionally cruising). The generation during deceleration is termed regenerative braking. When a vehicle decelerates frequently, such as during urban deliveries, hybrid powertrains considerably reduce fuel consumption. However, the batteries and electric machines add weight (Santini et al. 2005). Hydraulic hybrids are also an option.

reduces GPLTMT for the reference fuel, natural gas supplants all of the reference fuel. So, even though battery energy storage is less efficient than natural gas energy storage, far more energy is stored in natural gas tanks in a natural gas truck than is electricity in the battery of a hybrid. Because less range (than for combination trucks) is needed in normal single-unit truck use, compressed natural gas (CNG) can be fitted onto the frame rail. Further, since single-unit trucks operate usually at part cargo load, the extra mass of CNG tanks is acceptable. For Class 8 combination trucks, the energy storage limitations of natural gas require that it be cooled and liquefied to provide adequate range. The liquefied natural gas (LNG) is stored in cryogenic tanks. The weight of the tanks may be an issue, slightly reducing cargo load of the many class 8 combination trucks that operate with maximum cargo load.

This page intentionally left blank.

13 REFERENCES

answers.com, undated, *Diesel Engine — Advantages and Disadvantages Versus Spark-Ignition Engines,* http://www.answers.com/topic/diesel-engine (accessed Dec. 19, 2008).

Associated Press, 1982, "Bigger Heavier Trucks OK'd as U.S. Hikes Taxes," *Chicago Tribune*, Section 4, p. 8, Dec. 27.

Bayok, I., et al., 2002, "Flight from Blight vs. Natural Evolution: Determinants of Household Residential Location Choice and Suburbanization," presented at American Agricultural Economics Association Meeting, Long Beach, CA, July 28–31.

Bertram, K., et al., 1983, *A Summary of Truck Fuel-Savings Measures Developed with Industry Participation*, ANL/CNSV-TM-135, prepared by Argonne National Laboratory, Argonne, IL, for U.S. Department of Energy, Office of Vehicle and Engine Research and Development, Sept.

Boyer, K.D., and S.V. Burks, 2006, "Stuck in the Slow Lane: Traffic Composition and the Measurement of Labor Productivity in the Trucking Industry," Discussion Paper 2576, Forschunginstitute zur Arbeit Institute for the Study of Labor, Bonn, Germany, Jan.

Browning, L., 2002, *Update Heavy-Duty Engine Emission Conversion Factors for MOBILE6 — Analysis of BSFCs and Calculation of Heavy-Duty Engine Emission Conversion Factors, M6.HDE.004*, EPA420-R-02-005, prepared by ARCADIS Geraghty & Miller, Inc., for U.S. Environmental Protection Agency, Motor Vehicle Emissions Laboratory, Ann Arbor, MI, Jan.

Browning, L., 1998, *Update Heavy-Duty Emission Conversion Factors for MOBILE6 — Analysis of Fuel Economy, Non-Engine Fuel Economy Improvements and Fuel Densities, M6.HDE.004*, EPA420-P-98-014, prepared by ARCADIS Geraghty & Miller, Inc., for U.S. Environmental Protection Agency, Motor Vehicle Emissions Laboratory, Ann Arbor, MI, May.

Bureau of Transportation Statistics, 2004, "New Passenger Car and Light Truck Sales: Model Years 1980–2002," Figure 15 in *Pocket Guide to Transportation,* U.S. Department of Transportation, http://www.bts.gov/publications/pocket_guide_to_transportation/2004/pdf/entire.pdf (accessed May 2009).

Bukey, A., and B. Davies, 1991, "Sequenced Delivery: A True Application of Just-in-Time," *Industrial Engineering*, Norcross, GA, Dec., http:www.pincorp.com/PublishedPapers/Scheduling%20Publications/SequencedDeliveryATruApplicationOfJustInTime.pdf (accessed May 2007).

Burks, S.V., et al., 2004a, "Trends in Use of Large Trucks by Truckload and Less-Than-Truckload Carriers in the 1990s," *Journal of the Transportation Research Forum* 43:2, fall.

Burks, S.V., et al., 2004b, *How Many Trucks, How Many Miles, Trends in the Use of Heavy Freight Vehicles in the U.S., from 1977 to 1997,* University of Minnesota, Morris, MN, and California State University, Long Beach, CA.

Church, N., 2005, "Why Our Food Is So Dependent on Oil," *Energy Bulletin*, published by Powerswitch, U.K., Apr. 1, http://www.energybulletin.net/5045.html (accessed Dec. 19, 2008).

Cox, W., and J. Love, 1996, *The Best Investment a Nation Ever Made: A Tribute to the Dwight D. Eisenhower System of Interstate and Defense Highways,* prepared for American Highway Users Alliance, June.

Davis, S.C., and S.W. Diegel, 2006, *Transportation Energy Data Book: 25th Edition,* Report ORNL-6974, Oak Ridge National Laboratory Oak Ridge, TN.

Diesel Technology Forum, 2001, *Engineering Clean Air: The Continuous Improvement of Diesel Engine Emission Performance,* p. 4, Herndon, VA, March.

DOC (U.S. Department of Commerce), undated, "Real Gross Domestic Product, Chained Dollars," Table 1.1.6 in *National Economic Accounts Web-Based Interactive Tables*, Bureau of Economic Analysis, http://bea.gov (accessed July 27, 2007).

DOE (U.S. Department of Energy), 2003, *Just the Basics — Diesel Engine,* Office of Energy Efficiency and Renewable Energy, Washington, D.C., Aug., http://www.eere.energy.gov/vehiclesandfuels/pdfs/basics/jtb_diesel_engine.pdf (accessed Dec. 19, 2008).

EIA (Energy Information Administration), 2007, "Fuel Oil and Kerosene Sales: 1984–2005," Table 5.15 in *Annual Energy Review,* U.S. Department of Energy, Washington, D.C., http://www.eia.doe.gov/emeu/aer/petro.html (accessed July 24, 2007).

EIA 2006, "Estimated Petroleum Consumption: by End Use Sector, 1949–2003," Tables 5.13a through 5.13d in *Annual Energy Review,* U.S. Department of Energy, Washington, D.C., http://www.eia.doe.gov/emeu/aer/petro.html (accessed Aug. 1, 2006).

EIA, 2004, "Adjusted Sales of Distillate Fuel Oil by End Use in the United States, 1986–2002," Table 13 in *Fuel Oil and Kerosene Sales*, DOE/EIA-0535 (2003 and earlier versions), U.S. Department of Energy, Washington, D.C.

Eisenhower, D.D., 1967, *At Ease: Stories I Tell My Friends*, Doubleday Publishing, as cited in Schultz 2006.

Fedrizzi, R., and J. Rogers, 2002, *Energy Efficiency Opportunities: Big Box Retail and Supermarkets*, The Center for Energy and Climate Solutions Division, The Global Environment and Technology Foundation, May, http://files.harc.edu/Sites/GulfCoastCHP/MarketAssessments/EnergyEfficiencyOpportunitiesBigBox.pdf (accessed May 2009).

Ford, H., 2005, *My Life and Work*, Project Gutenberg EBook 7213, Jan., http://www.gutenberg.org/dirs/etext05/hnfrd10.txt (accessed Dec. 19, 2008).

Foss, A., 2006, "Streamline Your Business — Shortcuts Can Help You Profit in a New Market," *Professional Builder*, Reed Publications, Aug. 1, http://www.housingzone.com/probuilder/article/CA6357027.html (accessed Dec. 19, 2008).

FHWA (Federal Highway Administration), 1997a, "Functional Classification," Chapter 3 in *Flexibility in Highway Design*, U.S. Department of Transportation, http://www.fhwa.dot.gov/environment/flex/ch03.htm (accessed Dec. 19, 2008).

FHWA, 1997b, Tables VM 201 and VM201A in *Highway Statistics to 1995,* U.S. Department of Transportation, Washington, D.C.

FHWA, 1997c, "Special Fuels Use, 1982 and 1984," Table MF 221 in *Highway Statistics to 1995,* U.S. Department of Transportation, Washington, D.C.

FHWA, 2002, "From Push to Pull Logistics," *The Freight Story: A National Perspective on Enhancing Freight Transportation*, U.S. Department of Transportation, Freight Management and Operations, Washington, D.C.

FHWA, 2004, Table VM-1 in *Highway Statistics 2003,* U.S. Department of Transportation, Washington, D.C.

FHWA, 2005, Table VM-1 in *Highway Statistics 2004,* U.S. Department of Transportation, Washington, D.C.

Garreau, J., 1991, *Edge City: Life on the New Frontier*, Doubleday, New York, N.Y.

Gold, A., 2009, "Diesel Engine Characteristics," http://cars.about.com/od/dieselvehicles/a/What_is_diesel.htm (accessed May 2009).

Goldstein, S.H., 2006, "Convoy Celebrates Anniversary," *Light & Medium Diesel Truck*, p. 11, July.

Govindarajan, V., and J.B. Lang, 2002, *WalMart Stores Inc.,* case study, Tuck School of Business, Dartmouth College, Hanover, N.H.

Haight, B., 2004, "A Plan for Every Part: Manufacturers Fine-Tune Just-in-Time Delivery to Better Serve an Evolving Supply Chain," *Automotive Industries*, Aug., http://www.findarticles.com/p/articles/mi_m3012/is_8_184/ai_n6173990 (accessed Dec. 19, 2008).

Kelley, K., 1993, "Trucks and Bodies: What's in Store for '94," *Waste Age,* Oct. 1.

Lang, R.E., and P.A. Simmons, 2001, *Boomburbs: The Emergence of Large, Fast-Growing Suburban Cities in the United States,* Census Note 06, Fannie Mae Foundation, Washington, D.C.

Leichenko, R.M., 2001, “Growth and Change in U.S. Cities and Suburbs,” *Growth and Change* 32:326−354, summer.

Mikelbank, B.A., 2006, “Local Growth Suburbs: Investigating Change within the Metropolitan Context,” *Opolis 2*(1):1−15.

Port Authority of New York and New Jersey, 2003, *McGreevey Meets with Port Industry Leaders; Lays First Track for New Ship-to-Rail Facility at NJ Port,* Press Release 55-2003, Apr. 29.

Roberts, P., 2001, “Bad Sports, or: How We Learned to Stop Worrying and Love the SUV,” *Harpers Magazine,* Apr. 1, http://stayfreemagazine.org/suv/harpers.html (accessed Jan. 6, 2009).

Rodrigue, J.-P., 2004, “The Port of New York and New Jersey: Global Changes, Regional Gains and Challenges in Port Development,” Third Version, in *Les Cahiers Scientifiques du Transport*, Feb.

Santini, D.J., et al., 2005, “An Examination of the Potential for Regenerative Braking for a Range of Driving Cycles and Two Vehicle Configurations,” in *Proceedings of EVS-21, the 21st Worldwide Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exposition,* Monaco, Apr. 2–6.

Scania Trucks, undated, *A Century on the Road: 1902–2002,* p. 6, http://toolkitstatic.scania.com/scaniaworld.

Schultz, J.T., 2006, “A Rough Trip,” *Light & Medium Diesel Truck*, pp. 10–11, July (see Eisenhower 1967 re: title).

Solman, P., 2004, *WalMart — The Global Giant,* Online NewsHour, Public Broadcasting System, Aug. 20, http://www.pbs.org/newshour/bb/business/july-dec04/wal-mart_8-20.html (accessed Dec. 19, 2008).

Stone, K.E., undated, *Competing with the Mass Merchandisers,* Iowa Small Business Development Center, U.S. Small Business Administration, http://uwadmnweb.uwyo.edu/sbdc/pages_media/articles/articles/500/doc564.pdf.

Sullivan, L., 2005, “Ford Motor Enlists RFID [Radio Frequency Identification] Just-In-Time Delivery Systems,” *Information Week*, TechWeb News, Nov. 2, http://www.informationweek.com/news/mobility/RFID/showArticle.jhtml?articleID=173402517 (accessed Nov. 19, 2008).

The Road Information Program, 2004, *America’s Rolling Warehouses*, Washington, D.C., Feb., http://www.tripnet.org/TruckingReport020904.pdf (accessed Dec. 19, 2008).

Thomson Corporation, undated, "SIC 3713: Truck and Bus Bodies," *Encyclopedia of American Industries*, http://www.referenceforbusiness.com/industries/Transportation-Equipment/Truck-Bus-Bodies.html (accessed Dec. 19, 2008).

Truck Trend, 2002, "Tech: Gas vs. Diesel — Long Term Maintenance and Durability, Advantage: Diesel," Oct., http://www.trucktrend.com/features/tech/163_0210_gas/index2.html (accessed Dec. 19, 2008).

United States Code, 1982, Title 23, "Highways," Section 127, "Vehicle Weight Limitations," http://www.nap.edu/openbook.php?record_id=10382&page=215 (accessed May 2009).

U.S. Bureau of the Census, 1977, 1982, 1987, 1992, 1997, 2002, and 2006, *Truck Inventory and Use Survey* and *Vehicle Inventory and Use Survey* summaries and micro-data files.

U.S. Bureau of the Census, 2000a, *Population Estimates Program, Metropolitan Areas,* as cited in Leichenko, 2001.

U.S. Bureau of the Census, 2000b, *Population Estimates Program, Populations of Cities,* as cited in Leichenko, 2001.

U.S. Department of Housing and Urban Development, 1997, *The State of the Cities,* Office of Policy Development and Research, June, as cited in Leichenko, 2001.

Vyas, A, et al., 2002, *The Potential Effect of Future Energy-Efficiency and Emissions-Improving Technologies on Fuel Consumption of Heavy Trucks,* ANL/ESD/02-4, Argonne National Laboratory, Argonne, Ill.

Weisbrod, G., 2006, "Industries on the Interstate: What's the Best Location?" Number 244, *T.R. News,* Transportation Research Board News Magazine, May–June.

This page intentionally left blank.

APPENDIX A:

CRITERIA USED TO SELECT SAMPLE AND TOTAL TRUCK POPULATION AND CRITERIA USED TO SELECT TRUCK CLASS GROUPS

Criteria Used to Select TIUS 1982 and VIUS 2002 “Sample” Population

Use: Commercial trucks only (personal-use trucks dropped)

Fuel: Gasoline or diesel only

Trucks: Trucks with any one of these attributes were dropped from the “sample” population:

Classified as “not in use”
Classified as “off road”
Unknown GVW class
Unknown truck type (must be “single unit” or “combination”)
Unknown empty weight
Unknown laden weight
Unknown annual miles traveled
Unknown trip length (area of operation)
Fuel economy of ≤ 1.0 mpg
Fuel economy of more than three times the average GVW class mpg
Cargo weight of <200 pounds
Laden weight of more than the upper weight limit for the GVW class
Empty weight falling outside the 50% high or 50% low range for the GVW class

Criteria Used to Select TIUS 1982 and VIUS 2002 “Total” Population

Use: Commercial trucks only (personal-use trucks dropped)

Fuel: gasoline or diesel only

Trucks: Trucks with any one of the following attributes were dropped from the “total” population:

Classified as “not in use”
Classified as “off road”
Unknown GVW class
Unknown truck type (must be “single unit” or “combination”)

Trucks that have certain “missing” attributes (value not supplied by survey respondent) were “plugged” with average values:

Those having unknown mpg were assigned an average mpg for their GVW class and body type

Criteria Used to Select TIUS 1982 and VIUS 2002 Truck Class Groups

At least 30 records were required in order for data that were sorted into truck Categories 1–8 by various subcategories (e.g., gasoline versus diesel, usual operating area of ≤50 miles versus >50 miles) to be used in the tables and text analyses in this report.

APPENDIX B:

NUMBER OF TIUS/VIUS SAMPLE RECORDS, 1982–2002

TABLE B-1 Number of TIUS/VIUS Sample Records, 1982–2002[a]

Truck Class	Usual Area of Operation (mi)	TIUS 1982 No. of Sample Records		VIUS 2002 No. of Sample Records	
		Gasoline	Diesel	Gasoline	Diesel
1	≤50	1,938	16[b]	332	85
	>50	231	7[b]	78	20[b]
	All	2,169	23[b]	410	105
2	≤50	4,805	68	1,752	1,020
	>50	833	34	314	272
	All	5,638	102	2,066	1,292
3	≤50	2,551	99	1,286	1,449
	>50	442	57	284	541
	All	2,993	156	1,570	1,990
4	≤50	1,510	119	506	779
	>50	295	49	74	291
	All	1,805	168	580	1,070
5	≤50	1,760	179	571	735
	>50	307	78	129	321
	All	2,067	257	700	1,056
6SU	≤50	4,361	656	1,113	1,832
	>50	621	321	147	643
	All	4,982	977	1,260	2,475
6C	≤50	82	73	2[b]	18[b]
	>50	18	51	1[b]	31
	All	100	124	3[b]	49
7SU	≤50	1,710	625	539	1,346
	>50	220	248	48	464
	All	1,930	873	587	1,810
7C	≤50	100	185	0[b]	113
	>50	24[b]	150	1[b]	74
	All	124	335	1[b]	187
8SU	≤50	1,471	3,398	581	7,833
	>50	207	870	42	1,970
	All	1,678	4,268	623	9,803

TABLE B-1 (Cont.)

Truck Class	Usual Area of Operation (mi)	TIUS 1982 No. of Sample Records		VIUS 2002 No. of Sample Records	
		Gasoline	Diesel	Gasoline	Diesel
8C	≤50	482	4,037	21[b]	5,210
	>50	145	10,710	0[b]	10,356
	All	627	14,747	21[b]	15,566

[a] For data to be used in this report's tables and analytical findings, there had to be at least 30 records for gasoline and diesel trucks.

[b] Fewer than 30 records.

Source: DOC, 1982 TIUS data (2006 census release and 2002 VIUS)

APPENDIX C:

FHWA ESTIMATE OF REDUCTION IN PASSENGER VEHICLE FUEL CONSUMPTION

The passenger vehicles in Table C-1 include passenger cars, light trucks with two axles and four tires, and motorcycles and buses. From 1982 through 2002, the fuel efficiency (gallons per mile or gal/mi) of passenger cars improved from 0.0592 to 0.0452 gal/mi (16.9 to 22.1 miles per gallon or mpg), which represents a reduction in fuel consumption of 23.5%. For "other 2-axle, 4-tire vehicles" (light trucks), the improvement was from 0.0741to 0.0568 gal/mi (13.5 to 17.6 mpg), which represents a reduction in fuel consumption of 23.3%. In contrast to the positive cargo-hauling commercial truck (CHCT) mix-shift effects, the entire fleet of passenger vehicles did not achieve the rate of reduction in fuel consumption achieved by either the passenger cars or light trucks. The reason was the negative mix-shift effect from the change in the composition of vehicle holdings and vehicle miles of travel (VMT). With less-efficient light trucks gaining market share in the 1982–2002 period, negative mix effects caused the net improvement in fuel consumption for the passenger vehicle fleet to be less than that it would have been if the share of passenger cars and light trucks had remained the same. The result was that, on the basis of FHWA estimates and the measure of "fuel used per passenger mile of travel" (a measure logically comparable to the CHCT measure of "fuel used per cargo ton-mile"), there was a reduction of about 21% in the amount of passenger fleet fuel consumed per passenger mile (Table C-1). Since this percentage reduction was the same as that we estimate here for CHCTs for the 1982–2002 period, in terms of their reduction in fuel consumption per unit of physical service provided, the fleet of CHCTs improved to the same degree as the fleet of highway passenger-carrying vehicles.

TABLE C-1 Reduction in Gallons of Fuel Consumed per Passenger Mile and Vehicle Mile for All Passenger Vehicles,[a] 1982–2002

Year	Fuel Use (gal/ passenger mile)[b]	Total Number of Vehicles	Total Fuel Use (10^3 gal)	Passenger Miles Traveled (10^6 mi)	VMT (by all vehicles) (10^6 mi)	Use (gal/ vehicle mile)[b]	Average VMT by One Vehicle (mi)
1982	0.0373	159,806,683	92,998,067	2,493,536	1,483,587	0.0627	9,284
2002	0.0296	226,696,855	131,881,969	4,452,435	2,640,905	0.0499	11,649
Change (%)	−20.6	42	42	79	78	−20.3	25.5

[a] Include cars, motorcycles, buses, and other 2-axle, 4-tire vehicles.

[b] Columns two and seven show estimated average passenger occupancy per mile.

Sources: FHWA 1997b, 2004

Argonne
NATIONAL LABORATORY

Energy Systems Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 362
Argonne, IL 60439-4815

www.anl.gov

U.S. DEPARTMENT OF
ENERGY

A U.S. Department of Energy laboratory
managed by UChicago Argonne, LLC