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Factors and Considerations for Establishing a Fuel Efficiency Regulatory Program for Commercial Medium- and Heavy-Duty Vehicles

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List of Abbreviations

ALVW	adjusted loaded vehicle weight
AMT	automated manual transmission
APU	auxiliary power units
AT	automatic transmission
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CCPPR	capital cost per percent reduction
CD	coefficient of aerodynamic drag
CFD	computation fluid dynamics
CIL	component-in-the-loop
CFD	computational fluid dynamics
CRR	coefficient of tire rolling resistance
DEF	diesel emissions fluid
DF	deterioration factor
DOHC	dual overhead cam
DPF	diesel particulate filter
EGR	exhaust gas recirculation
EISA	Energy Independence and Security Act of 2007
EPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
ePTO	electric power takeoff
FC	fuel consumption
FE	fuel economy
FI	fuel injection
FMVSS	Federal Motor Vehicle Safety Standard
Gal	gallon
GDI	gasoline direct injection
GHG	greenhouse gas
GVWR	gross vehicle weight rating
HCCI	homogeneous charge compression ignition
HEV	hybrid electric vehicle
HD	heavy duty, heavy-duty
HFET	highway fuel economy test
HHD	heavy-heavy-duty
HHDDT	heavy-heavy-duty diesel truck
HHV	hydraulic hybrid vehicle
HIL	hardware-in-the-loop
HP	horse power
HPCR	high-pressure common rail
HPh	horse power hour
ICCT	International Center for Clean Transportation
IFTWG	Intermodal Freight Technology Working Group
ITS	intelligent transportation system(s)
Kg	kilogram

kW	kilowatt
kWh	kilowatt hour
Lb	pound
LB GDI	lean-burn gasoline direct inject
LCV	longer combination vehicle
LHD	light-heavy-duty
LSFC	load-specific fuel consumption
LTCCS	large truck crash causation study
MD	medium duty, medium-duty
MDPV	medium-duty passenger vehicle
MHD	medium-heavy-duty
MOVES	the EPA’s MOtor Vehicle Emission Simulator, and its database
MPG	miles per gallon
MPH	miles per hour
NPRM	Notice of Proposed Rulemaking
NAS	National Academy of Sciences
NESCCAF	Northeast States Center for a Clean Air Future
NHTSA	National Highway Traffic Safety Administration
NOx	oxides of nitrogen
NRC	National Research Council
O&M	operations and maintenance
OBD	onboard diagnostics
OHV	overhead valve
ORC	organic Rankine cycle
PCCI	premixed charge compression ignition
PFI	port fuel injection
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
RIA	regulatory impact analysis
RMC	ramped-modal cycle
RPE	retail price equivalent
SAE	Society of Automotive Engineers
SwRI	Southwest Research Institute
SCR	selective catalytic reduction
sGDI	stoichiometric gasoline direct injection
SOHC	single overhead cam
TT	tractor trailer
UDDS	Urban Dynamometer Driving Schedule
VG	variable geometry
VMT	vehicle miles traveled
VVA	variable valve actuation
VVL	variable valve lift
VVT	variable valve timing
WBS	wide-base singles (for tire)
WHTC	world-harmonized test cycle
Wt	weight

I. Introduction – What is the purpose of this study?

NHTSA undertook this study in response to the Energy Independence and Security Act (EISA) of 2007, in which Congress required both the National Academy of Sciences (NAS) and NHTSA to conduct studies to help inform NHTSA's development of a new regulatory system to improve the fuel efficiency of medium- and heavy-duty trucks. Two years were allotted from the beginning of the NAS study for both studies to be completed. The NAS study was made public on March 31, 2010, and the NHTSA study was designated for completion by the end of September 2010.

The context for NHTSA's study changed with the President's request in May 2010 that NHTSA and the Environmental Protection Agency (EPA) immediately begin work on a new joint rulemaking to establish fuel efficiency and greenhouse gas emissionstandards for medium- and heavy-duty trucks with the aim of issuing a final rule by July 30, 2011, over a year ahead of the schedule implied in EISA.[1] NHTSA and EPA determined that in order to allow sufficient time for public comment and for the agencies to respond sufficiently to those comments in the final rule, a Notice of Proposed Rulemaking should be released no later than October 2010. NHTSA and EPA's basic approach of the joint NPRM for this first phase of the "HD National Program" is to accomplish the initial possible fuel consumption and GHG reductions quickly by capturing low-hanging fruit. The agencies are able to meet the President's ambitious time table for regulation in part because of their relatively simplified approach, which is different from the more holistic and complicated approach envisioned by NAS, but that should contribute to significant improvements in fuel efficiency while minimizing the impact on the segments of the medium- and heavy-duty truck industry that are more complicated to regulate given their diversity.

Given that this study has been conducted in the context of the first phase of the HD National Program, and given that much work had already been done with EPA by the time of the President's announcement of the rulemaking time table, the NHTSA study constitutes a companion document to the NPRM that is being released concurrently. This document helps to explain NHTSA's decisions in the NPRM in the context of the tasks given to NHTSA by Congress in EISA, and to relate the NAS recommendations to the agency's decisions in a more detailed way than NHTSA and EPA were able to include in the accompanying NPRM.

[1] Presidential Memorandum: "Improving Energy Security, American Competitiveness and Job Creation, and Environmental Protection Through a Transformation of Our Nation's Fleet of Cars And Trucks," issued May 21, 2010, published at 75 Fed. Reg. 29399 (May 26, 2010), also available at www.whitehouse.gov/the-press-office/presidential-memorandum-regarding-fuel-efficiency-standards (last accessed Sept. 19, 2010). *See* Section II.C below for more information on EISA's implied schedule for rulemaking.

II. EISA's framework for developing MD/HD fuel efficiency regulations

With the passage of EISA in December 2007, Congress laid out a framework for developing the first fuel efficiency regulations for MD/HD vehicles. As codified at 49 U.S.C. § 32902(k), EISA requires NHTSA to develop a regulatory system for the fuel economy of commercial MD/HD on-highway vehicles and work trucks in three steps: a study by the NAS, a study by NHTSA, and a rulemaking to develop the regulations themselves. Although the text of the statute does not clearly mandate that the steps occur in sequence, they are most straightforwardly explained in turn.

A. NAS Study

Section 108 of EISA states that the Department of Transportation (by delegation, NHTSA) must execute an agreement with the NAS "to develop a report evaluating MD/HD truck fuel economy standards, including—

> **(1)** an assessment of technologies and costs to evaluate fuel economy for MD/HD trucks;
>
> **(2)** an analysis of existing and potential technologies that may be used practically to improve MD/HD truck fuel economy;
>
> **(3)** an analysis of how such technologies may be practically integrated into the MD/HD truck manufacturing process;
>
> **(4)** an assessment of how such technologies may be used to meet fuel economy standards to be prescribed under 49 U.S.C. § 32902(k); and
>
> **(5)** associated costs and other impacts on the operation of MD/HD trucks, including congestion."

EISA further states that the NAS must submit the report to DOT, the Senate Committee on Commerce, Science, and Transportation, and the House Committee on Energy and Commerce not later than one year after the date on which the Secretary of Transportation executed the agreement with the NAS. NAS requested and was granted an additional six months to complete its report; thus, based on the date of execution of the ultimate agreement, the deadline for the NAS report was determined to be March 2010.[2]

The NAS Report, "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles" (the "March 2010 NAS report" or "NAS report"), was delivered to NHTSA in pre-publication form in mid-March 2010, to

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[2] The modification to the contract is available at Docket No. NHTSA-2010-0079.

Congress in late March 2010, and was released to the public on March 31, 2010.[3] The contents of the NAS MD/HD study will be discussed below.

B. NHTSA Study

Section 102 of EISA, codified at 49 U.S.C. § 32902(k)(1), states that not later than one year after the NAS MD/HD study is published, DOT (by delegation, NHTSA), in consultation with DOE and EPA, "shall examine the fuel efficiency of commercial MD/HD on-highway vehicles and work trucks and determine

> **(A)** the appropriate test procedures and methodologies for measuring the fuel efficiency of such vehicles and work trucks;
>
> **(B)** the appropriate metric for measuring and expressing commercial MD/HD on-highway vehicle and work truck fuel efficiency performance, taking into consideration, among other things, the work performed by such vehicles and types of operations in which they are used;
>
> **(C)** the range of factors, including, without limitation, design, functionality, use, duty cycle, infrastructure, and total overall energy consumption and operating costs that affect commercial MD/HD on-highway vehicle and work truck fuel efficiency; and
>
> **(D)** such other factors and conditions that could have an impact on a program to improve commercial MD/HD on-highway vehicle and work truck fuel efficiency."

In response to the request from Senator Daniel Inouye that NHTSA complete its study within 24 months,[4] NHTSA determined that its study would need to be completed by September 2010.[5] This document constitutes the NHTSA study, in fulfillment of 49 U.S.C. § 32902(k)(1).

C. Rulemaking to Develop Regulations

Section 102 of EISA, codified at 49 U.S.C. § 32902(k)(2), states that not later than two years after completion of the NHTSA study, DOT (by delegation, NHTSA), in consultation with DOE and EPA, shall develop a regulation to implement a "commercial

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[3] National Academy of Science, Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles," March 2010 (hereafter, "March 2010 NAS report" or "NAS report"). Available at www.nap.edu/catalog.php?record_id=12845 (last accessed Sept. 19, 2010).

[4] *See* letter from Senator Inouye to DOT Secretary Peters, October 28, 2008. Available at Docket No. NHTSA-2010-0079.

[5] The study itself was fundamentally complete by the end of September, but the agency took an additional two weeks for clean-up and finalization of the document.

MD/HD on-highway vehicle and work truck fuel efficiency improvement program designed to achieve the maximum feasible improvement." NHTSA interprets the timing requirements as permitting a regulation to be developed earlier, rather than as requiring the agency to wait a specified period of time.

Congress specified that as part of the "MD/HD fuel efficiency improvement program designed to achieve the maximum feasible improvement," NHTSA must adopt and implement

(1) appropriate test methods;

(2) measurement metrics;

(3) fuel economy standards;[6] and

(4) compliance and enforcement protocols.

Congress emphasized that the test methods, measurement metrics, standards, and compliance and enforcement protocols must all be *appropriate*, *cost-effective*, and *technologically feasible* for commercial MD/HD on-highway vehicles and work trucks. These criteria are different from the "four factors" of § 32902(f)[7] that have long governed NHTSA's setting of fuel economy standards for passenger cars and light trucks, so we have italicized them here for emphasis.

Congress also stated that NHTSA may set separate standards for different classes of MD/HD vehicles, and provided requirements new to § 32902 in terms of timing of regulations, stating that the MD/HD standards adopted as a result of the agency's rulemaking shall provide not less than four full model years of regulatory lead time, and three full model years of regulatory stability.

II. What were the major findings and recommendations of the March 2010 NAS report?

As discussed above, Section 108 of EISA required that NHTSA contract with the NAS to undertake a study and develop a report that evaluated medium- and heavy-duty truck fuel economy. The National Research Council (NRC) Committee to Assess Fuel

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[6] In the context of § 32902(k), NHTSA interprets "fuel economy standards" as referring not specifically to miles per gallon, as in the light-duty vehicle context, but instead more broadly to account as accurately as possible for MD/HD fuel *efficiency*. While it is a metric that NHTSA considered for setting MD/HD fuel efficiency standards, the agency recognizes that it may not be an appropriate one given the work that MD/HD vehicles are manufactured to do, and thus is proposing alternative metrics in the NPRM that this report accompanies. This issue will be discussed further below.

[7] 49 U.S.C. § 32902(f) states that "When deciding maximum feasible average fuel economy under this section, [NHTSA] shall consider technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy."

Economy Technologies for Medium- and Heavy-Duty Vehicles was formed to fulfill the contract between NHTSA and the NAS.[8] Interpreting the tasks listed in Section 108 of EISA, NAS directed the committee to

- consider approaches to measuring fuel economy for medium- and heavy-duty vehicles that would be required for setting standards;
- assess current and potential technologies and estimate improvements in fuel economy for medium-duty and heavy-duty trucks that might be achieved;
- address how the technologies identified in the task above may be used practically to improve medium-duty and heavy-duty truck fuel economy;
- address how such technologies may be practically integrated into the medium-duty and heavy-duty truck manufacturing process;
- assess how such technologies may be used to meet fuel economy standards;
- discuss the pros and cons of approaches to improving the fuel efficiency of moving goods as opposed to setting vehicle fuel economy standards; and
- identify the potential costs and other impacts on the operation of medium-duty and heavy-duty trucks.[9]

The March 2010 NAS report spanned eight chapters, the major findings and recommendations of which we summarize by chapter and discuss below.

A. Introduction and Vehicle Fundamentals, Fuel Consumption, and Emissions (Chapters 1 and 2)

The NAS committee provided factual background for the reader in Chapter 1, discussing the policy motivation for improving the fuel efficiency of medium- and heavy-duty trucks; the weight classes and use categories that make up the broader group of medium- and heavy-duty trucks; energy consumption trends and trucking industry activity; factors affecting improvements in fuel consumption; and the committee's task organization and execution. We briefly summarize the committee's discussion of these issues below:

<u>Policy motivation</u>: The United States has a significant interest in reducing its dependence on imported petroleum, of which medium- and heavy-duty trucks are major consumers, and in reducing greenhouse gas (GHG) emissions, which are the natural by-product of fuel consumption. Over the past several decades, while CAFE standards for passenger cars and light trucks have contributed to reduced fuel consumption for light-duty vehicles, medium- and heavy-duty trucks have not improved in this regard.[10] The committee noted, however, that although fuel consumption by MD/HD vehicles has remained roughly constant, when considering total fuel consumed, total miles traveled, and total tons shipped over the same period, the amount of fuel required to move a given amount of freight a given distance (i.e., gallons/ton-mile) has been reduced by more than

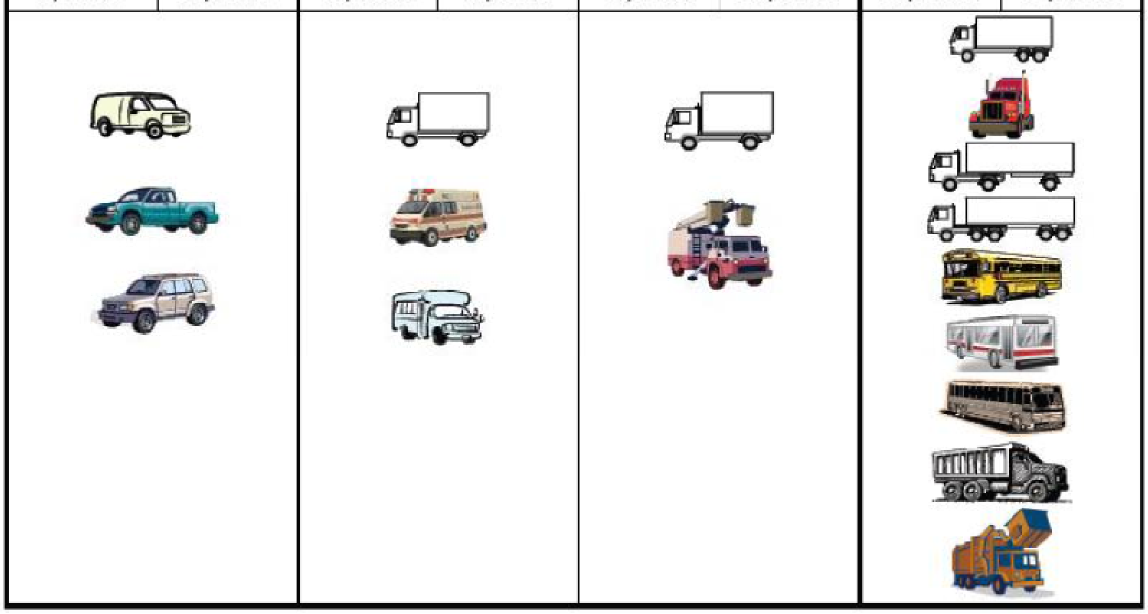
[8] March 2010 NAS report, at 9.
[9] Id., at 9-10.
[10] Id. at 11.

half over this time period.[11] The committee postulated that this was partly due to technology improvements that improved efficiency, partly due to regulations allowing longer, wider, and taller trailers and heavier loads, and partly due to trucking companies' operational efficiency improvements.[12] However, the committee emphasized, the increase in annual vehicle miles traveled (VMT) by MD/HD vehicles has overwhelmed the efficiency improvements over the past several decades,[13] leading fuel consumption to appear static.[14]

<u>Weight classes and use categories</u>: The committee presented the following table to describe the commonly referred-to weight classes and use categories for MD/HD vehicles:

Figure II.A.1 -- NAS Report Figure 1-4: Illustrations of typical vehicle weight classes (source: Davis et al., 2009, pp. 5-6)

Light-Duty		*Medium Heavy-Duty*				*Heavy-Duty*	
Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Less than 6,000 lb	6,000 to 10,000 lb	10,000 to 14,000 lb	14,000 to 16,000 lb	16,000 to 19,500 lb	19,500 to 26,000 lb	26,000 to 33,000 lb	Greater than 33,000 lb



The figure above helps to illustrate the diversity of medium- and heavy-duty vehicles in the market. It is based on the DOT classification system using a truck's gross vehicle weight rating (GVWR),[15] which is the manufacturer's stated maximum allowable weight

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[11] Id.
[12] Id.
[13] The committee noted that VMT may have decreased somewhat since the recession of the last couple of years, but that since the report was based on 2007 data, the recession and any decrease in VMT would not be evident in this analysis. Id. at 12.
[14] Id. at 11.
[15] The DOT GVWR vehicle classification system traces its origins to NHTSA's GVWR classes established in 49 CFR Part 565, the regulation for vehicle identification numbers. *See* Table II in 49 CFR § 565.15.

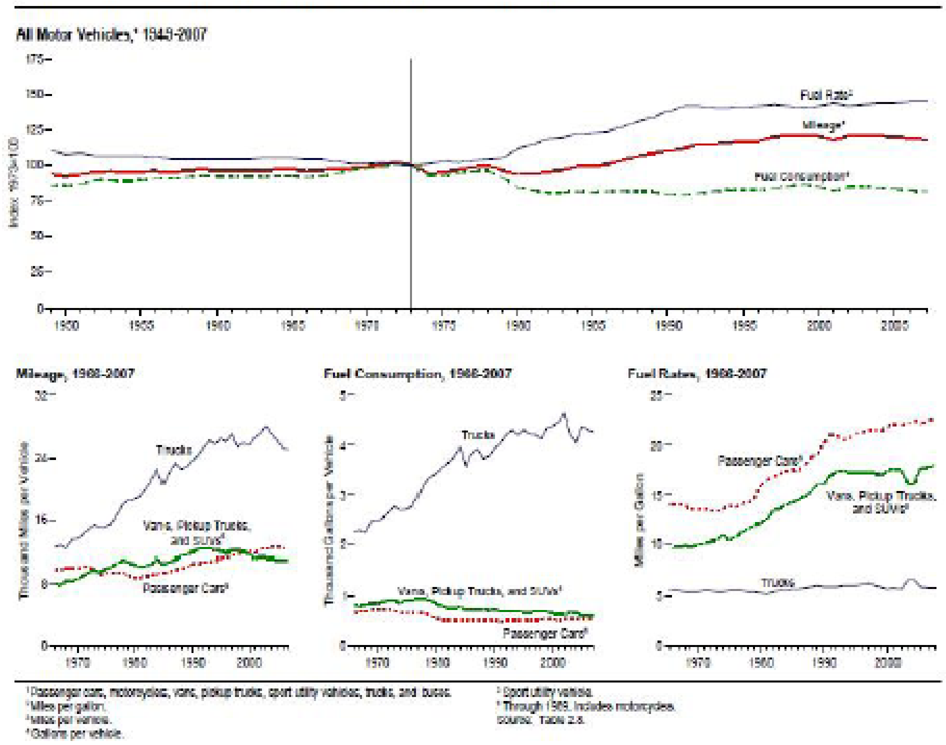
of a single vehicle. The GVWR for what could be considered MD/HD vehicles range from 8,500 lbs. to greater than 33,000 lbs. The committee offered the following summary observations about each of the vehicle classes:

- Class 1 and 2 vehicles lighter than 10,000 lbs. are generally considered light trucks, such as pickups, small vans, and sport utility vehicles. They are generally spark-ignited, gasoline-fueled, internal combustion engines and more than 80 percent are for personal use. This class of vehicle up to about 8,500 lb. comes under CAFE requirements for cars. Class 2 trucks with GVWR above 8,500 lb. are similar to Class 3 trucks.
- Class 3 and above are primarily commercial vehicles. A mix of gasoline and diesel engines is used in Classes 3 through 7, and diesel engines are almost exclusively used in Class 8.
- Classes 3 through 6 are medium- and heavy-duty vehicles with single rear axles.
- Classes 7 and 8 are heavy-duty vehicles with two or more rear axles.
- Class 8 combination trucks have a tractor and one or more trailers and a gross combined weight (GCW) of up to 80,000 lbs., with higher weights allowed in specific circumstances.[16]

Energy consumption trends and trucking industry activity: The committee stated that the number of MD/HD trucks and their VMT have increased substantially as the U.S. economy has grown over the past several decades, and emphasized again that increases in energy consumption for these vehicles is due to VMT increases more than any changes in actual fuel efficiency.[17] VMT has grown more quickly in the trucking sector than in the light-duty sector, resulting in medium- and heavy-duty vehicles taking up a growing share of total transportation-related petroleum consumption.[18] If current trends continue, heavy vehicles will consume an important fraction of the fuel used for on-the-road vehicles.[19] Considering the period from 1970 to 2003, energy consumption by lightweight trucks grew 4.7 percent annually, while that of passenger cars grew only 0.3 percent.[20] Meanwhile, energy consumption by heavy trucks increased 3.7 percent annually.[21] Figure 1-3 from the NAS report displays this divergence in growth.

[16] March 2010 NAS report, at 12-13.
[17] Id. at 13.
[18] Id. at 12.
[19] Id.
[20] Id. at 13.
[21] Id.

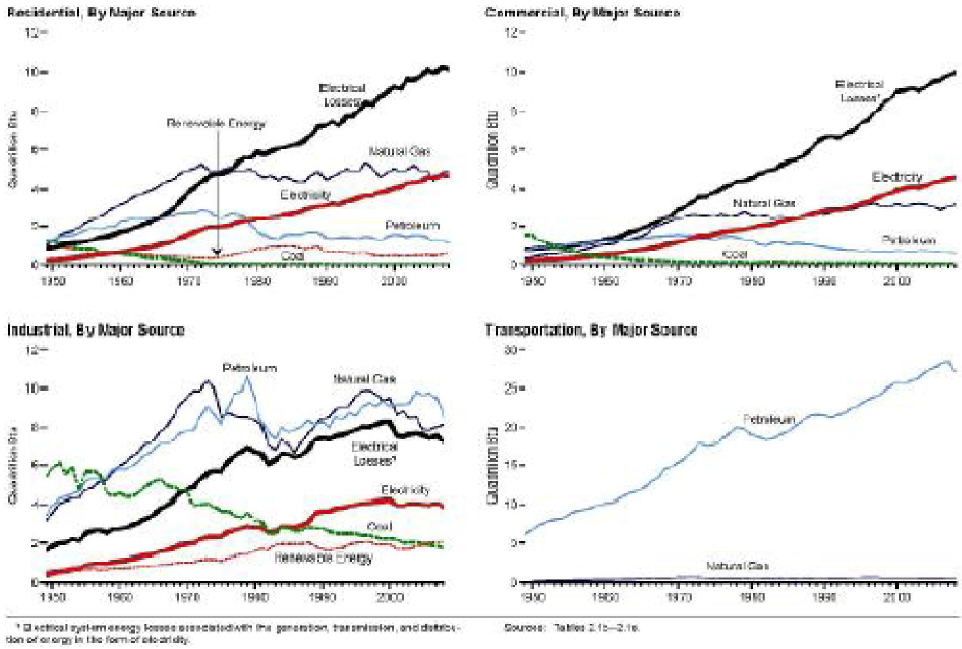
Figure II.A.2 -- NAS Report Figure 1-3: Motor vehicle mileage, fuel consumption, and fuel rates (source: DOE, EIA [2009a, Figure 2.8])



The U.S. transportation system relies nearly exclusively on petroleum, as shown in Figure 1-1 from the NAS report below. Coupled with a growing dependency each year despite attempts to substitute other fuels and energy sources, if the United States is to reduce its reliance on foreign sources of oil, it will be necessary to reduce the fuel consumption of medium- and heavy-duty vehicles.[22]

[22] Id. at 11-12.

Figure II.A.3 -- NAS Report Figure 1-1: Energy consumption by major source end-use sector, 1949-2008 (source: DOE, EIA [2009b, p. 39])

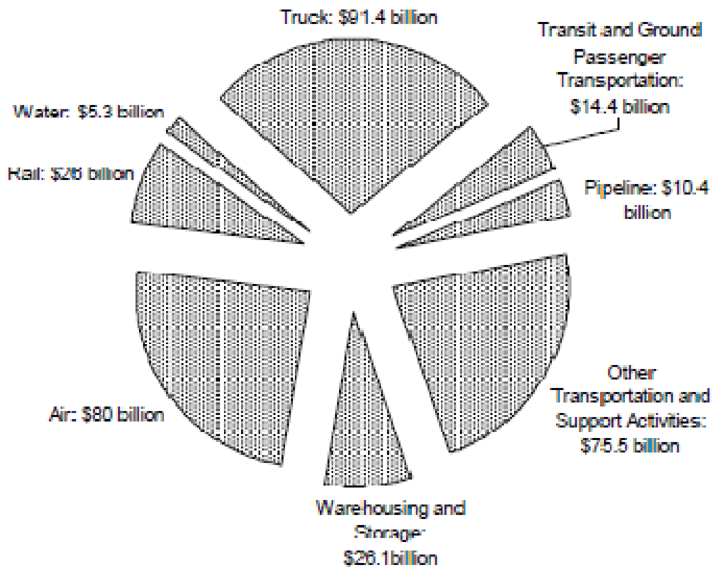


The committee also noted that the truck transportation industry was made up of more than 112,000 separate establishments, with total revenues of $165 billion, that employ 1.4 million workers who take home an annual payroll of $47 billion.[23]

Trucks and trucking are important contributors to the national income, and comparing the trucking industry's economic contribution with other industries in the transportation sector, about one-fourth of the sector's total revenues is attributed to these vehicles, as shown in the figure below.[24]

[23] Id. at 13, citing the Economic Census of 2002.
[24] Id.

Figure II.A.4 -- NAS Report Figure 1-5: For-hire transportation services' total revenue compared with other sectors of the transportation industry (source: DOC, Census Bureau [2005])



Factors affecting improvements in fuel consumption: The committee noted that MD/HD vehicles are designed to carry loads in an efficient and timely manner, which makes them different from light-duty vehicles.[25] Thus, because MD/HD vehicles are designed to carry payload, and because the loaded weight of a truck may be more than double the empty weight, the committee stated that the way to best represent an appropriate attribute-based fuel consumption metric is to normalize the fuel consumption to the payload that the vehicle hauls.[26] The committee recommended a metric called "load-specific fuel consumption" or "LSFC," measured in gallons/payload tons-100 miles.[27] The committee stated that the average payload value used for potential standards should be based on national data representative of the class and duty cycle of the vehicle.[28]

Task organization and execution: The committee stated that it had created four working groups to divide up tasks and relied on specialized consultants to execute various portions of the study, as follows:

- TIAX, LLC, developed detailed forecasts of fuel consumption reducing technologies, focusing on a 10-year timeframe.
- DOE's Argonne National Laboratory provided quantitative data as well as modeling and simulation analyses.

[25] Id. at 14.
[26] Id.
[27] Id.
[28] Id.

- Cambridge Systematics, Inc., and Eastern Research Group, Inc., examined possible consequences/unintended effects of regulations and examined alternative approaches to improving MD/HD fuel efficiency.

These consultant reports are available through NAS and also in the docket for this study and the accompanying NPRM.

In Chapter 2, the committee addressed the makeup of the trucking industry and the complexity of the trucking sector; metrics of vehicle fuel economy/consumption and their measurement; and the importance and diversity of vehicle duty cycles for different vehicle applications.

The makeup of the trucking industry and its complexity: The committee emphasized the wide range of vehicles that make up the MD/HD industry, which it indicated are generally classified by weight based on their gross vehicle weight rating (GVWR) into classes "2b" through "8."[29] GVWR is defined as the maximum in-service weight set by the manufacturer, and includes the empty weight of the vehicle plus the maximum allowed cargo load. Expanding on the table above, the committee offered the following table comparing the characteristics of vehicles in these different weight classes:

[29] Id. at 17.

Table II.A.1 -- NAS Report Table 2-1: Comparing Light Duty Vehicles with Medium and Heavy Duty Vehicles

Class	Applications	Gross Weight Range (lb.)	Empty Weight Range (lb.)	Typical Payload Capacity Max (lb.)	Payload Capacity Max (% of Empty)	2006 Unit Sales Volume	2006 Fleet Registrations (millions)	Typical mpg Range 2007	Typical Ton-mpg	Typical Fuel Consumed (1000 gals/Ton-Mi) x1000	Annual Fuel Consump-tion Range (gal)	Annual Fleet Fuel Consump-tion (Bgal)	Annual Mileage Range (1000mi) est.	Annual Fleet Miles Traveled 2006 (B)
1c	Cars *only*	(3200)-6000	2400 to 5000	250-1000	10-20	7,781,000	135	25-33	15	69.0	250-750	74.979	6-25	1,682
1t	Minivans, Small SUVs, Small Pick-Ups	(4000)-6000	3200 to 4500	250-1,500	8-33	6,148,000	70	20-25	17	58.8	300-1k	37.400	6-25	813
2a	Large SUVs, Standard Pick-Ups	6001-8500	4500 to 6000	250-2500	6-40	2,030,000	23	20-21	26	38.5	500-1.2k	18.000	10-25	305
2b	Large Pick-Up, Utility Van, Multi-Purpose, Mini-Bus, Step Van	8501-10,000	5,000 - 6,300	3700	60	545,000	6.2	10-15	26	38.5	1.5k-2.7k	5.500	15-40	93
3	Utility Van, Multi-Purpose, Mini-Bus, Step Van	10,001-14,000	7,650 - 8,750	5250	60	137,000	0.69	8-13	30	33.3	2.5k-3.8k	1.462	20-50	12
4	City Delivery, Parcel Delivery, Large Walk-in, Bucket, Landscaping	14,001-16,000	7,650 - 8,750	7250	80	48,000	0.29	7-12	42	23.8	2.9k-5k	0.533	20-60	4

Table II.A.1 -- NAS Report Table 2-1: Comparing Light Duty Vehicles with Medium and Heavy Duty Vehicles

5	City Delivery, Parcel Delivery, Large Walk-in, Bucket	16,001-19,500	9,500 - 10,800	8700	80	41,000	0.17	6-12	39	25.6	3.3k-5k	0.258	20-60	2
6	City Delivery, School Bus, Large Walk-in, Bucket	19,501-26,000	11,500-14,500	11,500	80	65,000	1.71	5-12	49	20.4	5k-7k	6.020	25-75	41
7	City Bus, Furniture, Refrigerated, Refuse, Fuel Tanker, Dump, Tow, Concrete, Fire Engine, Tractor-Trailer	26,001-33,000	11,500-14,500	18,500	125	82,411	0.13	4-8	55	18.2	6k-8k	1.926	75-200	9
8a	Dump, Refuse, Concrete, Furniture, City Bus, Tow, Fire Engine (straight trucks)	33,001-80,000	20,000-34,000	20,000 to 50,000	100-150	45,600	0.43	2.5-6	115	8.7	10k-13k	3,509	25-75	12
8b	Tractor-Trailer: Van, Refrigerated, Bulk Tanker, Flat Bed (combination trucks)	33,001-80,000	23,500-34,000	40,000 to 54,000	125 to 200	182,395	1.72	4-7.5	155	6.5	19k-27k	28.075	75-200	142

The committee noted that this wide variety of physical characteristics for MD/HD vehicles is both a function of and contributes to their extremely wide variety of uses.[30]

The committee also addressed the issue of the entities to be regulated, given the diversity of the industry. While a relatively small number of entities control large numbers of Class 8 tractors, for example, the committee emphasized that small family-owned fleets are also important parts of the MD/HD system.[31] Reporting that the 200 largest private and for-hire freight-hauling fleets controlled nearly 11 percent of all HD vehicles,[32] and that owner-operators controlled another 14 percent of the fleet, the committee concluded that small family-owned fleets would make up the remaining 75 percent of Class 4 through 8 trucks, and stressed that these fleets could face the greatest potential compliance burdens under any regulatory system. The committee stressed that the complexity and diversity of the industry would complicate efforts to regulate MD/HD vehicle fuel consumption, since market share between manufacturers shifts year to year (perhaps more significantly than light-duty market share shifts among those manufacturers); since truck body builders are the manufacturers of record for many medium-duty trucks, but may have little influence over the vehicle's fuel consumption; and since tractors and trailers are never built and rarely owned by the same company, which discourages holistic approaches to reducing fuel consumption.[33]

The committee also noted sales trends in the MD/HD industry, specifically that for most classes sales have decreased around 30 percent between 2004 and 2008,[34] with "profound fluctuations" in Class 8 engines and vehicles particularly due to a 2006 pre-buy to avoid cost increases and 2007 emission controls, followed by the current U.S. recession.[35]

<u>Metrics to determine the fuel efficiency of vehicles</u>: The committee discussed the difference between fuel *economy* (a measure of how far a vehicle will go on a gallon of fuel) and fuel *consumption* (the inverse measure, of how much fuel is consumed in driving a given distance) as potential metrics for MD/HD regulations.[36] Noting the non-linear nature of fuel economy – e.g., that more fuel can be saved by increasing fuel economy from 14 to 16 mpg than from 30 to 32 mpg – and its potential to confuse consumers, the committee concluded that fuel economy would not be a good metric for judging the fuel efficiency of a vehicle, and stated that it would use fuel *consumption* throughout the report instead.[37]

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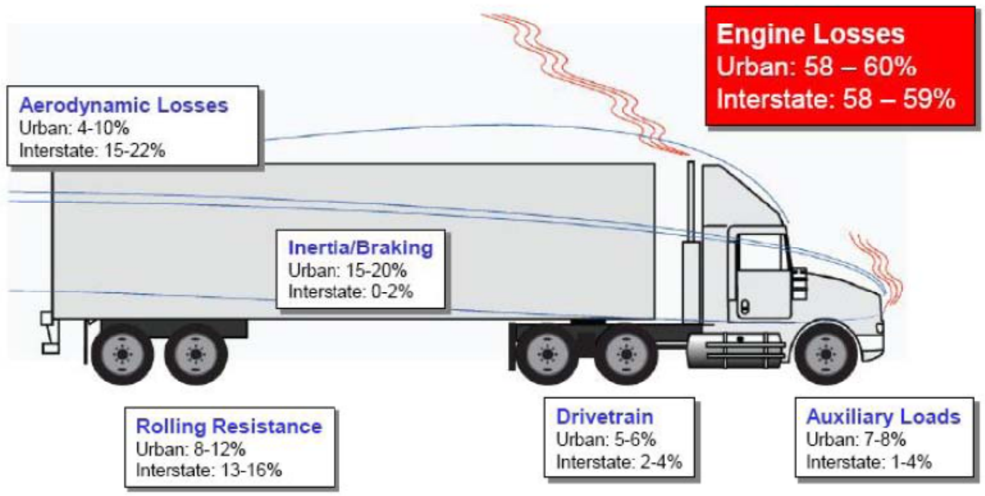
[30] Id.
[31] Id.
[32] Id., citing Bradley, M.J., and Associates LLC, Feb. 2009. Setting the Stage for Regulation of Heavy-Duty Vehicle Fuel Economy and GHG Emissions: Issues and Opportunities. International Council on Clean Transportation. Available at Docket No. NHTSA-2010-0079.
[33] Id. at 19-20.
[34] Id. at 19.
[35] Id.
[36] Id. at 22-25.
[37] Id. at 24.

However, because MD/HD vehicles are designed to carry loads in an efficient and timely manner, as opposed to light-duty vehicles that are generally used simply for carrying passengers, the committee suggested that normalizing the fuel consumption to the payload that the vehicle hauls would be the best way to represent an appropriate attribute-based fuel consumption metric.[38] The committee identified this metric as "Load-Specific Fuel Consumption" or "LSFC," defined as fuel consumption on a given cycle (in gallons/100 miles), divided by payload (in tons).[39] Thus, the committee noted, payload is a crucial variable that has significant impact on fuel consumption,[40] as is the duty cycle on which the vehicle operates, and the average vehicle speed.[41] The committee stated that any regulation should use an average payload based on national data for the average payload of various classes of MD/HD vehicles, and provided an appendix of national data for this purpose.[42] Then, the committee stated, NHTSA could use such data to determine a simple specific average or typical payload for each class and then for each separate vehicle application within each class for purposes of carrying out vehicle certification testing/simulation.[43] The committee emphasized that a specified typical payload would compel manufacturers to focus only on reducing fuel consumption, rather than trying to game the metric by changing payload.[44] The committee also cautioned, however, that unless the vehicle always operates at the same payload, the approach would not fully capture the vehicle's fuel consumption profile, and that there would consequently be a need for different standards for different vehicle classes and corporate fleet averaging.[45]

Truck tractive forces and energy inventory: While not a recommendation per se, the committee provided the following convenient summary of the fundamental vehicle attributes that account for fuel consumption as a basis for discussing the technologies that could reduce fuel consumption. Essentially, the committee described the force or power required to propel a vehicle at any moment in time as definable by a "road load equation," which evaluates the effect of tire rolling resistance, aerodynamic drag, acceleration and grade effects (both of which are affected by vehicle weight).[46] The committee presented a visual depiction (see the figure below) to illustrate how the extremes of duty cycles can create a wide range of impacts of these specific vehicle attributes to overall fuel consumption, as follows:[47]

[38] Id. at 25.
[39] Id.
[40] The committee also noted that while adding payload to a vehicle increases fuel consumption, the higher payload actually improves the efficiency of the vehicle in terms of LSFC, and that it would be important to bear that fact in mind to avoid creating regulations with severe unintended consequences.
[41] Id. at 25-27.
[42] Id. at 27.
[43] Id.
[44] Id.
[45] Id.
[46] Id. at 28.
[47] Id. at 29.

Figure II.A.5 -- NAS Report Figure 2-7: Energy "loss" range of vehicle attributes as impacted by duty cycle, on a level road.



The committee emphasized that when developing test cycles for engines or vehicles, it should be understood that any test cycle cannot hope to represent every in-use behavior.[48]

Test protocols: The committee considered both physical testing and computer simulation as potential ways to evaluate fuel consumption. For physical testing, the committee explained that options included on-road testing and dynamometer testing, and stated that fuel use data from both kinds of physical testing could be used indirectly to calibrate whole-vehicle models where road load constants could not be determined for tire rolling resistance or coefficients of aerodynamic drag due to drivetrain loss offsets.[49] The committee then stated that the models could be used in turn to predict fuel consumption on unseen drive cycles.[50]

For on-road testing, the committee discussed SAE J1321, a fuel consumption procedure developed by the Society of Automotive Engineers and widely used by carriers and manufacturers for evaluating fuel economy, which measures on-road fuel consumption utilizing a similar control vehicle operated in tandem with a test vehicle to provide reference fuel consumption data.[51] The committee's analysis suggested that the SAE procedure was roughly 3 percent accurate (99 percent confidence) between the test vehicle and the control vehicle, but could cost $33,000 for an expert third-party lab to conduct.[52] The committee cautioned, however, that the lack of a systematic process for

[48] Id. at 28.
[49] Id. at 28-29.
[50] Id. at 29.
[51] Id.
[52] Id.

accounting for side winds (yaw conditions) was a significant shortcoming with the SAE J1321 procedure.[53]

For measuring aerodynamics, the committee discussed coast-down testing, wind tunnel testing, and computation fluid dynamics (CFD). Coast-down testing can be used to define a vehicle's rolling resistance and characteristic aerodynamic drag, but the committee stressed that it must be well regulated and that it can be imprecise and complicated by prevailing winds, vehicle mass, and the nature of the road surface.[54] The committee stated that wind tunnel testing is the only accurate method to measure aerodynamic drag force directly, because it can directly account for yaw (sideways) forces.[55] When possibly combined with CFD codes, which perform millions of computer calculations to simulate the interaction of fluids and gases with the complex exterior surfaces of the vehicle, the committee suggested that a wind tunnel approach was preferable for measuring aerodynamic drag.[56] For greater certainty, however, the committee suggested that the agency request the SAE's Truck and Bus Aerodynamic and Fuel Economy Committee to examine this issue in greater depth and provide recommendations with regard to the validation, accuracy, and precision of different measurement methods for aero drag, including SAE J1321, EPA's modification of SAE J1321, coast down, wind tunnel, CFD, and full-truck computer simulation testing.[57]

The committee stated that to characterize the fuel efficiency of a complete vehicle against a standard, it is essential to exercise the vehicle through a prescribed speed-time sequence that reasonably reflects actual use.[58] The committee noted that engineers typically assemble such cycles by combining real-world truck activity data and parsing it to come up with trips that are connected to form a cycle of desired length, which is then compared to other cycles to find the one that is statistically most representative of the trip characteristics in terms of average speed, standard deviation of speed, and so forth.[59] The committee identified several non-regulatory test cycles for combination tractors, vocational vehicles, and buses.[60] The committee stated that the average speed of a real-world cycle implies the level to which the cycle includes transient speed behavior,[61] and stressed that using average speed is important because vehicles in the real world do not operate at steady speeds but include transient behavior like idling, acceleration/deceleration, and so forth.

For vehicle simulation, the committee noted that it had employed vehicle modeling and simulation to assess the impact of current and future technologies on fuel consumption – specifically, the committee used Argonne National Laboratory's PSAT model – but that as a regulatory tool, it would be an ongoing challenge to make sure that

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[53] Id.
[54] Id.
[55] Id. at 30.
[56] Id.
[57] Id. at 30-31.
[58] Id. at 31.
[59] Id.
[60] Id. at 31-32.
[61] Id. at 32.

the simulation tools provide an adequate representation of actual vehicle performance and fuel consumption as new powertrain and vehicle technologies appear.[62] The committee emphasized that a model like PSAT is developed to focus on specific vehicles, and is different than a model used to analyze the effects of technology on fleets, like NHTSA's CAFE Compliance and Effects Model (frequently referred to as the Volpe model) used for light-duty fleet analysis.[63] The committee stated that simulation is increasingly important in vehicle development because it reduces the need for hardware testing and helps bring technologies to market faster, and to help predict the effect of combining systems that affect fuel consumption and performance as those systems become increasingly complex.[64] The committee suggested that techniques used by manufacturers in model-based design (MBD) could potentially be used for regulation, such as Japan's use of hardware-in-the-loop (HIL) simulation as part of its regulations.[65]

The committee noted, however, that models must be established using the appropriate datasets if they are to represent technologies properly.[66] The committee stated that while some phenomena are currently well understood and can be properly modeled, such as fuel consumption and performance within 1 to 2 percent, others remain difficult to address properly, such as criteria emissions or extreme thermal conditions.[67] The committee stressed that because criteria emissions cannot be simulated as accurately as fuel consumption and vehicle performance, there can be inherent inaccuracies in modeling fuel consumption in an emission-constrained vehicle, as all MD/HD vehicles are.[68] The committee suggested that more investigation should be conducted regarding the influence of fuel consumption reduction technologies on actual in-service emissions.[69]

B. Current Regulatory Approaches (Chapter 3)

In order to evaluate how various regulatory entities have addressed the complexity of regulating the diverse MD/HD fleet, the committee considered the regulatory approaches of the European Union (EU), Japan, EPA's SmartWay program, and California's SmartWay-based regulations, as well as NHTSA's light-duty fuel economy standards and EPA's HD criteria emissions regulations.

<u>European approach</u>:

The committee described a several-year study by the European Commission (EC) exploring test procedures and metrics for measuring fuel consumption and carbon dioxide (CO_2) emissions, that began looking at engines and eventually moved to the whole

[62] Id. at 36-37.
[63] Id. at 37.
[64] Id.
[65] Id. at 38.
[66] Id. at 37.
[67] Id.
[68] Id.
[69] Id.

vehicle, but ultimately concluded that the enormous complexity made a "one size fits all" approach to measuring fuel efficiency or CO_2 emissions infeasible.[70] The EC thus concluded that full vehicle testing for even a part of the fleet would be prohibitively costly.[71] However, the EC did determine that any metric should include some indication of the work done as well as the fuel used, such as liters of fuel per ton-kilometer.[72]

Picking up where the EC left off, the European Automobile Manufacturers Association began a project in 2009 to develop a methodology to evaluate HD vehicles' fuel efficiency using computer simulation,[73] aiming to create a fuel economy regulation for the EU in 2013-2014.[74] The proposed simulation tool could use standardized, generic, or specific input modules, depending on the application purpose.[75] Because truck and engine manufacturers in the EU are more integrated than in the United States, for example, it is expected that truck manufacturers will be the regulated entity.[76] The metric may vary depending on vehicle purpose, but would be work-based, such as fuel consumed per payload mass, payload volume, or number of passengers carried per distance traveled.[77]

Japanese approach:

Japan began its program to regulate HD truck fuel consumption in 2006 with a process of collaborative meetings with manufacturers, and has set a target implementation date for its regulations of 2015.[78] Japan will regulate vehicle manufacturers – even more so than in Europe, Japan's engine and vehicle manufacturers are highly integrated and relatively few, so this approach makes sense for them.[79] The metric used is kilometers/liter, with different standards for different weight classes.[80] Japan's system focuses on improvements to engines and not on improvements to the whole vehicle.[81]

Fuel consumption is evaluated through a computer simulation tool, which is publicly available online and which requires vehicle specifications and engine fuel maps as inputs.[82] Users can modify some inputs, such as transmission ratio, final drive ratio, wheel radius, and main engine characteristics, but not others, such as weight, frontal area, drag coefficients, component losses, or advanced shifting control algorithms, which means that manufacturers do not receive credit for improvements to those.[83] Hybrids are

[70] Id. at 41.
[71] Id.
[72] Id.
[73] Id., and Finding 3-2.
[74] Id.
[75] Id.
[76] Id.
[77] Id.
[78] Id. at 42.
[79] Id.
[80] Id.
[81] Id.
[82] Id.
[83] Id.

accounted for through HIL simulation, not as part of the main model.[84] Only two drive cycles can be selected, an urban cycle and an interurban cycle.[85]

The committee stressed that the Japanese example provided valuable input to the development of a U.S. regulatory system, insofar as Japan decided that the complexity of MD/HD vehicle configurations and duty cycles lent itself to the use of computer simulation as a cost-effective way of calculating fuel efficiency, even despite the fact that Japan's MD/HD industry is less diverse and more integrated than the U.S. industry.[86]

<u>EPA's SmartWay Program</u>:

EPA's voluntary SmartWay certification program for HD vehicles applies to new Class 8 sleeper trucks and dry van trailers, and requires participating manufacturers and fleets to use certain types of fuel-efficiency-improving technologies, in exchange for which vehicles may be labeled with the SmartWay logo to indicate environmental friendliness.[87] The tractor specifications include a number of aerodynamic features including a high-roof sleeper, integrated roof fairings, cab side extenders, fuel tank side fairings, and aerodynamic bumpers and mirrors; engines must be 2007 or newer with SmartWay-approved options for idle reduction; tires must be low rolling resistance; wheels may be aluminum for weight reduction.[88] No technical validation is required (except data for the tire rolling resistance) for certification, simply the presence of these technologies.[89]

The trailer specifications include aerodynamic features like side skirt fairings and a front gap or rear fairing;[90] tires must be SmartWay-approved low rolling resistance; and wheels may be aluminum for weight reduction.[91] Either new or retrofitted trailers may be SmartWay-certified.[92] The aero specification for trailers may also be met through physical testing if approved by EPA.[93]

<u>California's SmartWay mandate</u>:

In order to help California reduce its greenhouse gas emissions to 80 percent of 1990 levels by 2020, California developed regulations to require all MY 2011 sleeper cab tractors to be SmartWay-certified if they pull 53-ft or longer box van trailers.[94] Day cab tractors must have SmartWay-approved low rolling resistance tires.[95] In all MYs 2011

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[84] Id.
[85] Id.
[86] Id., and Finding 3-2.
[87] Id. at 43.
[88] Id.
[89] Id. at 43-44.
[90] EPA has validated trailer side skirts, trailer boat tails, and trailer gap reducers. *See* Id. at 44.
[91] Id.
[92] Id.
[93] Id.
[94] Id. at 45.
[95] Id.

and beyond, all 53-ft or longer van trailers (whether new or in-service) must be SmartWay-certified, with retrofits if necessary, although a phase-in is permitted for larger fleets from 2010 to 2015 and for smaller fleets from 2013 to 2016.[96] The committee stated that this mandate will have a significant impact on the number of vehicles in the United States that are specified with fuel-efficient technologies beginning in 2010.[97]

NHTSA's light-duty fuel economy standards:

The committee noted that the statutory framework established by Congress for the CAFE program sets a metric for the agency of miles per gallon (mpg) for expressing fuel economy standards,[98] and a test cycle for passenger cars that was established in 1975.[99] The test cycle is a combination of a city/urban cycle commonly referred to as the FTP (Federal Test Procedure), and a highway test cycle that represents a mix of rural and interstate highway driving. The committee described for some length the efforts undertaken by EPA to adjust the test procedures and the values resulting from them, which are significantly outdated given driving patterns today, in order to better represent real-world fuel economy for vehicle labeling purposes.[100] The committee noted that the test procedure is a physical chassis dynamometer test, which is very repeatable and precise, and that manufacturers conduct their own testing and submit the data to EPA, which may conduct confirmatory testing for 10 to 15 percent of light-duty vehicles itself.[101] The committee emphasized that despite the fact that CAFE was built on existing EPA emissions regulations, using the same testing protocols, that the time, and presumably effort, needed to implement CAFE and its test protocols were very substantial.[102]

HD engine emissions regulations:

The committee pointed to the example of EPA's HD engine emissions regulations as an instance in which the industry's diversity is addressed by requiring compliance at the component level, which reduces the regulatory burden on the final stage manufacturers and preserves the flexibility of assembly to meet customer demands.[103] The committee noted that there are a number of reasons to regulate engine manufacturers, including the fact that the chassis may be produced by a different manufacturer than the engine; that it is more efficient to hold a single entity responsible; and that testing an engine cell is more accurate and repeatable than testing a whole vehicle.[104] EPA's engine emissions standards are expressed in a metric of grams per horsepower-hours or kilowatt-hours, based on results from a transient test procedure conducted on an engine

[96] Id.
[97] Id., and Finding 3-4.
[98] Id.
[99] Id. at 46.
[100] Id.
[101] Id.
[102] Id.
[103] Id. at 47, and Finding 3-3.
[104] Id.

dynamometer.[105] Separate test procedure schedules are required for diesel and gasoline engines.[106] The committee noted that even with the simplified engine-only approach, the transient test procedures were under development at EPA for 5 years, and several years more were required for the industry to employ electric dynamometers, constant-volume samplers, dilution systems, and new measurement systems for PM.[107] The committee further noted that certification for engine emissions involves collaboration between EPA and manufacturers with respect to which engines fall into different "families," which are then all certified based on representative engines that are actually tested.[108] For enforcement, manufacturers gain compliance flexibility through a program of averaging, banking, and trading (ABT), either among engine families or among manufacturers, and a non-compliance penalty option is available if a manufacturer wants to certify to an emissions level higher than the standard.[109] The committee stated that Class 2b vehicles may also certify to the emissions requirements using a chassis cycle or schedule.[110]

NHTSA safety standard for HD vehicles:

The committee pointed to Federal Motor Vehicle Safety Standard (FMVSS) No. 121 as an example of a compliance mechanism that provides flexibility and minimizes burden on industry.[111] FMVSS No. 121 is a performance-based regulation that requires that a vehicle stop within a certain distance, depending on vehicle type, from an initial speed when loaded to the GVW rating.[112] The committee noted that brake performance evaluation requirements differed for tractors (which must use a test track) and trailers (which must use a dynamometer), as an illustration for how a given HD vehicle regulation can vary significantly depending on the vehicle unit.[113] The committee also stated that the fact that FMVSS No. 121 basically "cascades down" to the component manufacturer (because the final-stage manufacturer can assure compliance by using axle assemblies properly sized and rated for the load that the axle is designed to carry), it provides manufacturers with much more design flexibility.[114] The committee suggested that such an approach could be useful for regulating HD truck fuel consumption.[115]

C. Technologies and Direct Impacts (Chapters 4, 5, 6)

Our summary of these chapters will be considerably more brief than summaries of other chapters, largely due to the level of technical detail provided by the NAS committee and the difficulty in condensing it in a way that would be helpful to the reader here, but

[105] Id.
[106] Id.
[107] Id., citing Merrion, 2002.
[108] Id. at 48.
[109] Id. at 49.
[110] Id.
[111] Id.
[112] Id.
[113] Id.
[114] Id. at 49-50.
[115] Id. at 50.

also because the technologies themselves may not bear as directly on the objectives of NHTSA's study as other concerns evaluated by NAS for developing a regulatory framework. We note, for the reader's reference, that the majority of the NAS direct technology cost and effectiveness estimates are based on a report from TIAX, LLC, who was contracted to NAS to assess fuel economy technologies for MD/HD vehicles. The TIAX report is available in NHTSA's docket for the HD rulemaking, Docket No. NHTSA-2010-0079, which can be accessed at http://www.regulations.gov.

Chapter 4 considered powertrain technologies for reducing load specific fuel consumption, and presented technologies for improving the efficiency of diesel and gasoline engines (including fuels and emission systems) as well as technologies for transmissions and drive axles. It also discussed the role of hybrid powertrains (both electric and hydraulic) in reducing fuel consumption.

Diesel engine technologies: The committee stated that many individual technologies exist for reducing load-specific fuel consumption of diesel engines, with some being used in 2010 by nearly all manufacturers (such as common rail fuel injection), while others are used by a more limited number of manufacturers (turbocompounding and multiple turbochargers).[116] The committee noted that Cummins had shown a roadmap for improving diesel engine thermal efficiency to 49.1 percent by 2016 and 52.9 percent by 2019, which represented fuel consumption reductions compared to a 2008 baseline of 14.5 and 20.6 percent, respectively.[117] However, the committee cautioned that significant technical challenges remain to be overcome before many of the fuel-saving technologies considered by the committee could be successfully implemented in production.[118]

Below are two summary tables of the diesel engine technologies and their costs and effectiveness considered by the committee as provided in the TIAX report. The first table covers the estimates for 6-9 liter diesel engines, while the second covers estimates for 11-15 liter diesel engines.

[116] Id. at 86-87, Finding 4-1.
[117] Id. at 86.
[118] Id.

Table II.C.1: 6-9 Liter Engine Diesel Technology Matrix[119]

Description	FC Improvement	Capital cost (RPE)	Introduction	Baseline
Reduce Heat Transfer and Exhaust Losses				
High pressure fuel injection (up to 4,000 bar), multiple injections per cycle, rate shaping, etc	1 to 4%	$0 to $1,000	Continuous	1,800 to 2,200 bar; single injection/ cycle; common rail or unit FI
Increase cylinder pressure	1 to 4%	$500 to $1,500	Continuous	20 to 23 Bar
OBD w/Engine controls and sensors — closed loop control, run engine @ NOx limits across the map	1 to 4%	$60 to $150	2013	Open-loop electronic controls
Emissions Control				
Add SCR (optimizes engine for efficiency, not NOx) – includes 2% DEF penalty	2 to 3%	$7,000 to $8,000	2010	Medium-rate EGR (2007-compliant)
Improved NOx conversion efficiency	1 to 3%	$0	Continuous, post 2010	Cu-zeolite or Fe-zeolite for 2010; better catalysts, lower light-off temp can yield future benefits
Passive DPF regen and reduced back pressure	1 to 1.5%	$0	2010	Active Regen
High-Rate EGR	-1 to -2%	$6,000	2010	Medium-rate EGR, (2007-compliant)
Mixed-mode advanced combustion — (e.g., PCCI @ low/med load)	1 to 2%	$8,000	2012 to 2015	Medium-rate EGR, (2007-compliant)
	Up to 6%	**$7,000 to $8,000**	**Continuous**	**Medium-rate EGR, no SCR, Active regen**
	up to 12%	**$7,000 to $9,650**	**Continuous**	**~40 to 41% thermal efficiency**
Reduce Gas Exchange Losses				
VVA	1%	$300	2012	
Advanced low-temp EGR, lower pressure drop	0 to 1.5%	$500 to $750	2010 to 2013	High-rate EGR
Turbocharger efficiency and performance enhancements; e-turbo, super-charging, etc	1 to 3%	$0 to $1,000	Continuous	Multi-stage elec. actuated turbo
	up to 4%	**$0 to $2,050**	**Continuous**	**~40 to 41% thermal efficiency**
Reduce Friction - lubricants, bearings, etc				
	0.5 to 2%	**0 to $500**	**Continuous**	**~40 to 41% thermal efficiency**
Reduce Parasitic and Accessory Loads				
Incremental improvements to existing baseline	0 to 0.5%	$0 to $200	Continuous	Belt-driven mechanical accessories
Variable displacement pumps, incremental improvements	0.5 to 2%	$200 to $500	2012	Belt-driven mechanical accessories
Accessory Electrification -- Electric Auxiliaries (air compressor, power steering pump, air cond, fan,alternator, water pump); in combination with hybrid or other vehicle electrification.	1 to 3%	$1K to $2K (Low) $500 to $1,000 (High)	2012	Belt-driven mechanical accessories
	0 to 3%	**$0 to $2,000 Continuous**	**~40 to 41% thermal efficiency**	

[119] For the reader's reference, the TIAX report defines the term "continuous" used in the technology matrix tables in this section as referring to technologies that are continually being improved over existing designs with each successive technology generation. This makes it difficult to identify a precise year of introduction, hence the use of the term "continuous." *See* TIAX report, p. 3-4.

Table II.C.2: 11-15 Liter Engine Diesel Technology Matrix

Description	FC Improvement	Capital cost (RPE)	Intro Year	Baseline
Reduce Heat Transfer and Exhaust Losses				
High pressure fuel injection (up to 4,000 bar), multiple injections per cycle, rate shaping, etc	1 to 4%	$0 to $1,000	Continuous	1,800 to 2,200 bar; single injection/ cycle; common rail or unit FI
Increase cylinder pressure	1 to 3%	$500 to $1,500	Continuous	20 to 23 Bar
OBD w/Engine controls and sensors — closed loop control, run engine @ NOx limits across the map	1 to 3%	$60 to $150	2013	Open-loop electronic controls
Emissions Control				
Add SCR (optimizes engine for efficiency, not NOx) – includes 2% DEF penalty	2 to 3%	$9,000 to $10,000	2010	Medium-rate EGR (2007-compliant)
Improved NOx conversion efficiency	1 to 3%	$0	Continuous, post 2010	Cu-zeolite or Fe-zeolite for 2010; better catalysts, lower light-off temp can yield future benefits
Passive DPF regen and reduced back pressure	1 to 1.5%	$0	2010	Active Regen
High-Rate EGR	-1 to -2%	$8,000	2010	Medium-rate EGR, (2007-compliant)
Mixed-mode advanced combustion — (e.g., PCCI @ low/med load)	1 to 2%	$10,000	2012 to 2015	Medium-rate EGR, (2007-compliant)
	Up to 6%	**$9,000 to $10,000**	**Continuous**	**Medium-rate EGR, no SCR, Active regen**
	up to 10%	**$9,000 to $12,650**	**Continuous**	**~41 to 42% thermal efficiency**
Reduce Gas Exchange Loss Reduction				
VVA	1%	$300	2012	
Advanced low-temperature EGR, lower pressure drop	1 to 1.5%	$500 to $750	2010 to 2013	Medium rate cooled EGR, negative delta p
Turbocharger efficiency or advanced configurations (e-turbo, multi-stage, etc)	1 to 2%	$0 to $1,000	Continuous	VG turbocharger
	up to 3%	**$0 to $2,050**	**Continuous**	**~41 to 42% thermal efficiency loss**
Reduce friction - lubricants, bearings, etc				
	0.5 to 2%	**0 to $500**	**Continuous**	**~41 to 42% thermal efficiency loss**
Reduce Parasitic and Accessory Loads				
Incremental improvements to existing baseline	0 to 0.5%	$0 to $200	Continuous	Belt-driven mechanical accessories
Variable displacement pumps, incremental improvements	1 to 2%	$200 to $500	2012	Belt-driven mechanical accessories
Accessory Electrification — Electric Auxiliaries (alternator, air compressor, power steering pump, air cond, fan, fuel pump, water pump); in combination with hybrid or other vehicle electrification.	1 to 3%	$1,000 to $2,000	2012	Belt-driven mechanical accessories
	0 to 3%	**$0 to $2,000**	**Continuous**	**~41 to 42% thermal efficiency loss**
Recover Waste Heat				
Turbo-Compound – Mechanical	2.5 to 3%	$2,000 to $3,000	2010	No WHR
Electric Turbo-Compound, including accessory electrification	4 to 5%	$6,000 to $7,000 ($3,000 to $4,000 inc.to Hybrid)	2013	No WHR
Thermo-electric or thermo-acoustic	2 to 3%	?	2015	No WHR
Bottoming Cycle, Steam Cycle or ORC – 15 to 60 kW	6 to 10%	$7,200 to $15,100	2015	No WHR
	2.5 to 10%	**$2,000 to $16,000**	**2010**	**No WHR**

Gasoline engine technologies: For MD vehicles, the committee stated that technologies exist or are under development today that can potentially reduce the fuel consumption of gasoline-powered vehicles, but that the most beneficial technologies and the magnitude of fuel savings will depend on the engine's configuration and the duty cycle of its application.[120] The committee noted that under optimal matching of technology and duty cycle, fuel consumption reductions of up to 20 percent may be

[120] Id. at 86-87, Finding 4-2.

possible compared to 2008 gasoline engines in the 2015-2020 timeframe,[121] but the committee did not state necessarily that this should be required by a regulatory framework. The committee cautioned that the economic merit of integrating different fuel-saving technologies will be an important consideration for vehicle operators and owners in choosing whether to implement these technologies.[122] The committee recommended that the Federal government should continue to support research programs in industries, national labs, private consulting companies, and universities aimed at developing fuel-saving engine technologies and effectively integrating them into engines and powertrain systems.[123]

Below is a summary table of the gasoline engine technologies and their costs and effectiveness considered by the committee as provided in the TIAX report.

Table II.C.3: 5-8 Liter Engine Gasoline Technology Matrix

Description	FC Improvement	Capital cost (RPE)	Introduction	Baseline
Reduce Gas Exchange, Exhaust Heat, and Heat Transfer Losses				
VVT	1 to 3%	$122	2008	Gasoline, PFI, fixed valve w/reduced friction
VVL (Discrete or Continuous)	1 to 3.5%	$400 to $750	2008	Above + VVT
Stoichiometric GDI	2 to 3%	$512 to $930	2008	Above + VVL + Cylinder deactivation
Lean burn GDI	10 to 14%	$750	2012 + low sulfur fuel	Stoichiometric GDI
Turbo-charged, down-sized engine	2.1 to 2.2%	$1,229	2008	Stoichiometric GDI
Cylinder deactivation	2.5 to 3%	$75	2008	Baseline + VVL and VVT + reduced friction
Gasoline HCCI	10 to 12%	$685	?	Stoichiometric GDI
	Up to 15%	**$0 to $4,200**	**Continuous**	**Gasoline, PFI, fixed valve**
Reduce Friction - lubricants, bearings, etc				
	0.5 to 2.5%	**$110 to $500**	**Continuous**	**Gasoline, PFI, fixed valve**
Reduce Parasitic and Accessory loads				
Variable displacement pumps, incremental improvements	0.5 to 2%	$200 to $500	2012	Belt-driven mechanical accessories
Accessory Electrification — Electric Auxiliaries (air comp, ps pump, air cond, fan, alt, water pump); in combination with upgrade to 42V electrical system or hybrid.	1 to 3%	$1,000 to $2,000 (current) $500 (high volume)	2012	Belt-driven mechanical accessories
	0 to 3%	**$0 to $2,000**	**Continuous**	**Belt-driven mechanical accessories**

Diesel engines versus gasoline engines: The committee found that diesel engines can provide fuel consumption advantages, compared to gasoline engines, of 6-24 percent

[121] Id. at 87.
[122] Id.
[123] Id., Recommendation 4-1.

depending on application, duty cycle, and baseline gasoline engines.[124] However, the committee noted that emissions regulations that require aftertreatment equipment increase the cost of dieselization and decrease its prevalence, pointing to Class 6 trucks in the new sales fleet decreasing from 75.8 percent in 2004 to 58.0 percent in 2008 as diesel fuel prices rose in the same period.[125] The committee stated that while 2010 emission regulations had yet to impact the fleet at the time of writing, the expectation was that the trend toward gasoline engines in MD trucks would accelerate as a result.[126] The committee recommended that, given the high potential for reducing fuel consumption through dieselization, NHTSA should conduct a study of Class 2b-7 vehicles regarding gasoline versus diesel engines considering the incremental fuel consumption reduction of diesels, the price of diesel versus gasoline engines in 2010-2011, especially considering the high cost of diesel emission control systems, and the diesel advantage in durability, with a focus on the costs and benefits of the dieselization of this fleet of vehicles.[127]

Transmission and driveline technologies: The committee explained that the transmission ratio and axle ratio affect fuel consumption by determining the engine speed versus the road speed of the vehicle, so that a properly specified transmission and axle will allow the engine to run at its best fuel consumption operating range for a given road speed.[128] With regard to transmissions, the committee stated that manual transmissions have the least mechanical losses, but an automated manual transmission (AMT) can reduce fuel consumption (4 to 8% benefit) by reducing driver variability.[129] A fully automatic transmission can improve productivity (i.e., reduced trip times) by reducing the shift time (full-power upshifts) and by avoiding engine transient response delays, and can also reduce fuel consumption (up to 5%) by reducing driver variability, but has higher parasitic losses.[130] The committee recommended that the industry should continue its practice of training dealers and provide training material for truck specifications affecting fuel consumption such as transmission ratios, axle ratios, and tire size.[131]

Below is a summary table of the transmission and driveline technologies and their costs and effectiveness considered by the committee as provided in the TIAX report.

[124] Id., Finding 4-3.
[125] Id., Finding 4-4.
[126] Id.
[127] Id., Recommendation 4-2.
[128] Id., Finding 4-5.
[129] Id., Finding 4-6.
[130] Id.
[131] Id., Recommendation 4-3.

Table II.C.4: Transmission and Driveline Technology Matrix

Category	Technology	FC Benefit	Cd/Crr/Wt Change	Capital cost (RPE)	Intro Year	Sales Pen.	Baseline
Tractor Trailer	Appropriate spec-ing of truck: match the axles, transmission gears, etc for the intended route, road speeds, and vocation*	1 to 3%		—	Pre-2008	60-90%	10-speed manual, matched axles and gears
	Direct Drive	1 to 1.5%	—	—	Pre-2008	?	10-speed manual, matched axles and gears
	Friction Reduction	1 to 1.5%	—	$0 to $500	Continuous	—	10-speed manual, matched axles and gears
	Single drive axle	1%	—	$200 to $300	2012-2013	—	10-speed manual, matched axles and gears
	Automatic transmission	0 to 5%	+200 lbs	$15,000	2008	<5%	10-speed manual, matched axles and gears
	AMT/Optimized Shift Strategy	4 to 8%	+70 lbs	$4,000 to $5,700	2008	10%	10-speed manual, matched axles and gears
Refuse Hauler	Appropriate spec-ing: match the axles, transmission gears to the application	1 to 3%	—	—	Pre-2008	60 to 100%	6 speed AT
	Increased Transmission Gears – 6 spd to 8 spd AT	2 to 3%	—	$2,100 to $2,600	2010	—	6 speed AT
	Reduced AT parasitics and friction	1%	—	0 to $500	Continuous	—	6 speed AT
	Aggressive Shift Logic and Early Lockup	0.5 to 1%	—	$100	2010	—	6 speed AT, Conventional shift strategy
Transit Bus	Appropriate spec-ing: match the axles, transmission gears to the application	1 to 3%	—	—	Pre-2008	60 to 100%	6 speed AT
	Increased Transmission Gears – 6 spd to 8 spd AT	2 to 3%	—	$1,100 to $1,650	2010	?	6 speed AT
	Reduced AT parasitics and friction	1%	—	0 to $500	Continuous	—	6 speed AT
	Aggressive Shift Logic and Early Lockup	0.5 to 1%	—	$100	2010	—	6 speed AT, Conventional shift strategy
Class 3-6 box and bucket	Appropriate spec-ing: match the axles, transmission gears to the application	1 to 3%	—	—	Pre-2008	60 to 100%	6 speed AT
	Increased Transmission Gears – 6 spd to 8 spd AT	2 to 3%	—	$1,000 to $1,650	2010	?	6 speed AT
	Reduced AT parasitics and friction	1%	—	0 to $500	Continuous	—	6 speed AT
	Aggressive Shift Logic and Early Lockup	0.5 to 1%	—	$100	2010	—	6 speed AT, Conventional shift strategy
Class 2b	Improved controls - Aggressive Shift logic, early lock-up	1.5 to 2.5%	-	$60	2010	-	4-speed automatic transmission
	6-speed to 8-speed AT	2.7 to 4.1%	-	$500 to $1,650	2011	-	4-speed automatic transmission
	AMT	5.5 to 9.5%	-	$700 to $1,400	2011	-	4-speed automatic transmission
	Friction Reduction	0 to 1%	-	0 to $500	Continuous	-	-
	Lower Final Drive	2 to 3%	-	$-	2009	-	-
Motor Coach	Automatic Manual Transmission	4 to 8%	+70 lbs	-$10,000	2008	—	6 speed AT
	Appropriate spec-ing: match the axles, transmission gears to the application	1 to 3%	—	—	Pre-2008	60 to 100%	6 speed AT
	Increased Transmission Gears – 6 spd to 8 spd AT	1.5 to 2%	—	$1,870 to $2,200	2010	?	6 speed AT
	Reduced AT parasitics and friction	1 to 1.5%	—	0 to $500	Continuous	—	6 speed AT
	Aggressive Shift Logic and Early Lockup	1 to 2%	—	$100	2010	—	6 speed AT, Conventional shift strategy

Hybrid powertrains: The committee stated that fuel consumption reductions on hybrid vehicles of 5-50 percent have been reported by enabling optimum engine operation, downsizing in certain cases, braking energy recovery, accessory electrification, and engine shutdown at idle.[132] The committee noted that a wide range of hybrid electric and hydraulic architectures have been demonstrated, and that the selection of a particular system architecture depends mainly on application, duty cycle, and cost-benefit trade-offs.[133] The committee further noted that the realized fuel consumption benefits of a

[132] Id., Finding 4-7.
[133] Id., Finding 4-8.

particular hybrid technology and architecture implementation are strongly dependent on application and duty cycle, stating that optimization of component sizing and power management are keys to maximizing the potential for fuel consumption reductions while satisfying performance and emission constraints.[134] The committee suggested that computer simulation of MD/HD vehicles is an effective way to predict fuel consumption reductions considering the additional variables in a hybrid vehicle system, but expressed concern that such systems are not standardized, leading to a wide variety of results and unpredictability.[135] The committee recommended that NHTSA should support the formation of an expert working group charged with evaluating available consumer simulation tools for predicting fuel consumption reduction in MD/HD vehicles and developing standards for further use and integration of these simulation tools.

Below is a summary table of the hybrid powertrain technologies and their costs and effectiveness considered by the committee as provided in the TIAX report.

[134] Id., Finding 4-9.
[135] Id., Finding 4-10.

Table II.C.5: Hybrid Powertrain Technology Matrix[136]

Category	Technology	FC Benefit	Cd/Crr/Wt Change	Capital cost (RPE)	Intro Year	Sales Pen.	Baseline
Tractor Trailer	"Moderate Hybrid": Dual mode, all electric capability; Includes electrified accessories, overnight hotel loads, and engine-off at idle	6 to 9%	~750 lbs	$45 to $5K (Low) $25 to $30K (High)	2013	Demos	2007 Base engine
	"Mild Hybrid": 40 to 50 kW motor; Parallel, single motor and clutch; integrated hybrid assembly (motor, clutch, transmission) and power electronics (battery, inverters, controls); Includes electrified accessories, hotel loads, and engine-off at idle	5 to 7%	~ 500 lbs	$35 to $45K (Low) $20 to $25K (High)	2013	Demos	2007 Base engine
	Gen II hybrid: Integration w/engine and after-treatment — optimize engine operation; implemented on either hybrid package. Requires reg. change.	2 to 3%	—	—	2014-2015	—	Hybrid package
Refuse	Parallel HEV	20%	450 lbs	$35-$40K (Low)	2009	—	No Hybrid
	Parallel HEV, Future	25 to 30%	350 lbs	$18-$20K (High)	2014	—	No Hybrid
	Parallel HEV, ePTO	25%	650 lbs	$52K	2010	—	No Hybrid
	Parallel HEV, Future	30 to 35%	500 lbs	$25 to $30K	2014	—	No Hybrid
	Parallel HHV	20 to 25%	1,000 lbs	$40K (Low) $30K (High)	2009	—	No Hybrid
	Series HHV	40 to 50%	~1,500 lbs	$50K (Low) $40K (High)	2013	—	No Hybrid
	Integration of emissions control w/hybrid system	2 to 3%	—	—	2014-2015	—	No Hybrid
Transit Bus	Gasoline Series: 270 kW engine, 200 kW generator, 170 kW motor, 200 kW NiMH battery or ultracap	25 to 35%	2,000 lbs	$200,000 ($20K w/90% subsidy)	Pre-2008	150 on the road	No Hybrid
	Diesel Series: 270 kW engine, 200 kW generator, 170 kW motor, 200 kW NiMH battery or ultracap	30 to 40%	2,600 lbs	$220,000 ($22K w/subsidy)	Pre-2008	75 on the road	No Hybrid
	Diesel Parallel	22 to 35%	940 to 2,840	$200,000 ($20K w/subsidy)	Pre-2008	25 to 30%	No Hybrid
	Integration of emissions control w/hybrid system	2 to 3%	—	—	2014	—	No Hybrid
Class 3-6 Box and Bucket	Parallel HEV	20 to 25%	450 lbs	$35-$40K (Low)	2007	~1 to 2%	No Hybrid Technology
	Parallel HEV, Future (Engine-off at idle, electric accessories, optimized controls, lighter components, high volume production)	25 to 35%	350 lbs	$18-$20K (High)	2014	-	No Hybrid Technology
	Parallel HHV	20 to 25%	1,000 lbs	$40K (Low) $30K (High)	2011	-	No Hybrid Technology
	Series HHV	40 to 50%	~1,500 lbs	$50K (Low) $40K (High)	2013	-	No Hybrid Technology
	Parallel HEV w/ePTO	30 to 40%	650 lbs	$49 to $52K (Low)	2007	~1 to 2%	No Hybrid Technology
	Parallel HEV w/ePTO, Future ((Engine-off at idle, electric accessories, optimized controls, lighter components, high volume production)	35 to 45%	500 lbs	$25 to $30K (High)	2014	-	No Hybrid Technology
Class 2b	Elec. Acc.	2 to 4%	-	$500 to $2,000	2014	-	-
	• Package 1: VVT and VVL – gasoline	2.5 to 9%	-	$632 to $1,372	2010	-	Gasoline, PFI, fixed valve
	• Package 2: SGDI, VVL and VVT - gasoline	7 to 14%	-	$1,200 to $2,400	2012	-	Gasoline, PFI, fixed valve
	• Package 3: Turbo-charged gasoline, down-sized engine; Includes SGDI, VVLT	11 to 17%	-	$2,500 to $3,600	2012	-	Gasoline, PFI, fixed valve
	• Package 4: Diesel, turbo charged, HPCR (1,800 bar), NOx Adsorber or SCR	19 to 24%	+500 lbs	$7,900 to $9,400	2010	50%	Gasoline, PFI, fixed valve
	• Package 6: Improved Diesel - adopts higher FI, increased cylinder pressure, improved controls and turbo; similar to 2010-2012 HD tech	4 to 5%	-	$1,000 to $2,000	2012	-	Diesel Pkg 4
	Lean burn GDI	20 to29%	-	$3,250 to $4,350	2014	-	Gasoline, PFI, fixed valve
Motor Coach	Parallel HEV Line-haul "Mild Hybrid": 40 to 50 kW motor; Parallel, single motor and clutch	7 to 10%	500 lbs	$30 to $40K	2015	-	No Hybrid
	Parallel Diesel HEV Transit Bus	10 to 15%	1,000 to 2,000 lbs	$180,000 to $220,000 ($36 to $44K w/80% subsidy)	Available now	~5%	No Hybrid
	Gen II hybrid: Integration w/engine and after-treatment – optimize engine operation; implemented on either hybrid package	2 to 3%	-	? - should be nominal controls upgrade	2014-2015	-	No Hybrid

[136] For the reader's reference, the TIAX report differentiates capital costs in the table below by identifying costs in the "Capital cost" column as "Low" (meaning capital costs at low production volumes), "High" (meaning capital costs at high production volumes), and "w/subsidy" (meaning capital costs given a certain amount of government subsidy).

Chapter 5 considered vehicle technologies for reducing load-specific fuel consumption. The committee emphasized that the technologies that can be used to reduce fuel consumption in MD/HD vehicles vary by vehicle type, duty cycle, and the year that the technology becomes available – for example, a Class 8 tractor operating on the interstate will benefit from technologies that improve aerodynamic performance and reduce rolling resistance, but a Class 2b pickup truck will benefit little from these technologies. The chapter discusses vehicle energy balances and how energy is lost in the operation of MD/HD vehicles, and then reviews technologies and techniques for reducing the fuel consumption of these vehicles, including technologies that improve aerodynamic performance and that reduce rolling resistance, auxiliary loads, and idle. The chapter also covers mass/weight reduction, and intelligent vehicle technologies.[137]

The committee presented an energy balance for a Class 8 vehicle to map out how the energy contained in the fuel is used by the vehicle.[138] The committee discussed how energy is consumed (lost) by the engine through heat rejection to the coolant and heat loss through the exhaust, with the remaining energy being used to propel the vehicle down the road, including the energy required to overcome frictional and aerodynamic losses, and supply auxiliary loads such as the air compressor, cooling fans, air-conditioning compressor, power take-off (PTO), etc.[139] The committee also explained that the energy consumed by the different loss mechanisms and the energy required to propel the vehicle and supply auxiliary loads can vary based on the vehicle type and application.[140]

Aerodynamics: The committee stated that at highway speeds, aerodynamic loads consume more power than any other load on current tractor-trailer vehicles.[141] Aerodynamic features can significantly reduce these loads, but their value diminishes rapidly as average vehicle speed goes down, and in low-speed operation, aerodynamic features have little value.[142] The committee identified four areas of the tractor-trailer combination as critical for aerodynamic improvements: (1) tractor streamlining, (2) management of airflow around the tractor-to-trailer gap, (3) management of airflow under the trailer, and (4) management of airflow at the rear of the trailer.[143] The committee suggested that by the 2015-2020 timeframe, the use of aerodynamic features could provide fuel consumption reductions of about 15 percent for tractor-van trailer vehicles operating at 65 mph, but that the potential benefits for other classes of vehicles are significantly less.[144] The committee also cautioned that many tractor and trailer aerodynamic features are damage-prone in low-speed operation, and that the cost of repairing these features as they break may be a significant barrier to implementation for

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[137] Id. at 91.
[138] Id. at 91-92.
[139] Id.
[140] Id. at 92.
[141] Id. at 128, Finding 5-1.
[142] Id.
[143] Id., Finding 5-2.
[144] Id., Finding 5-3.

some applications, while broken aero components could also become road hazards.[145] The committee recommended that regulators require aerodynamic features to be evaluated on a wind-averaged basis that takes into account the effects of yaw, and that tractor and trailer manufacturers should be required to certify their drag coefficient results using a common industry standard.[146]

Below is a summary table of the aerodynamic feature technologies and their costs and effectiveness considered by the committee as presented in the TIAX report.

[145] Id., Finding 5-4.
[146] Id., Recommendation 5-1.

Table II.C.6: Aerodynamic Technology Matrix

Category	Technology	FC Benefit	Cd/Crr/Wt Change	Capital cost (RPE)	Intro Year	Sales Pen.	Vocation	Baseline
Tractor	Roof top fairing, sleeper cab	7 to 10% 1	5 to 20%	(Standard) $500 to $1,000	pre-2008	63%	Van TT only	No cab aero
	Roof top deflector, day cab	4 to 7%	13%	$1,000 to $1,300	pre-2008	Most	Day cabs only	No cab aero
	Cab Side extension (aka, "side fairing")	2 to 3%	4 to 5%	$300 to $500; (Standard on some vehicles)	pre-2008	80 to 90%	Any	No cab aero
	Chassis Skirts (aka, "chassis fairing", "fuel tank fairing") -— full length	3 to 4%	4 to 7%	$1,500 to $2,000	pre-2008	45 to 60%	Long Haul, sleeper cabs	No cab aero
	Chassis Skirts (aka, "chassis fairing", "fuel tank fairing") — partial length	2 to 3%	4 to 6%	$500 to $1,200	pre-2008		Day cabs primarily	No cab aero
	Baseline Package - Smartway Aero Cab: Aero mirrors, cab side extenders, integrated sleeper cab roof fairing, aero bumper, full fuel tank fairings;	4 to 6%	22 to 25%	$2,750 to $3,500	2008 to 2010	~60%	Van TT, primarily	Compared to no aero (CD of 0.8)
	"Next generation" Smartway aero cab: Current Smartway cab, PLUS aero bumper w/underbody treatment; improved streamlining; wheel skirts	3 to 4% beyond Smartway	6 to 8%	$2,750	2012	—	Van TT, primarily	Smartway cab
Trailer	Partial Skirts (4 to 6 m)	2 to 3%	2 to 6%	$1,500 to $2,000	2010 to 2012	Demos	Many types of trailers	53' box trailer
	Full Skirts (7 to 9 m)	4 to 5%	5 to 11%	$2,000 to $4,000	2010 to 2012	Demos	Many types of trailers	53' box trailer
	Partial Gap Fairing	1 to 2%	2 to 4%	$800 to $1,000	2010 to 2012	Demos	Van TT	53' box trailer; 42" gap
	Full Gap fairing	2 to 3%	4 to 6%	$1,000 to $1,500	2010 to 2012	Demos	Van TT	53' box trailer; 42" gap
	Boat tail — structural or inflatable	4 to 6%	6.5 to 9%	$1,500 to $2,000	2010 to 2012	Demos	Van TT	53' box trailer
	Bogie Fairing – fairing for the trailer rear wheel assembly	1%	~2%	$500	2010 to 2012	Demos	Any	53' box trailer
	Hub caps	0 to 0.5%	~1%	?	2010 to 2012	Demos	Any	53' Box trailer
	Pneumatic Aero Drag Reduction - Unproven	3.5 to 4.0%	?	$2,500 - $5,250	Post-2015	Demos	Van TT	53' box trailer
	Smartway trailer – partial skirts + partial gap fairing or boat tail	5 to 6%	10 to 12%	$3,000 per trailer	2010 to 2012	Demos	Van TT	53' box trailer
	Full next-generation trailer aero – full skirts, boat tail, and full gap fairing	8 to 9%	17 to 19%	$4,000 per trailer	2013 to 2015	—	Van TT	53' box trailer
Tractor + Trailer Aero Pkgs	No aero	-10 to -12%	-22 to -25%	-	Pre-2008	—	Van TT	Smartway Tractor, 53' trailer
	Smartway Tractor	-	CD ~ 0.59	-	Pre-2008	~60%	Van TT	Smartway Tractor, 53'
	Smartway Tractor + Smartway Trailer	5 to 6%	10 to 12%	$3,000 per trailer	2010 to 2012	Demos	Van TT	Smartway Tractor, 53' trailer
	Improved Smartway Tractor + Smartway Trailer	7 to 9%	5 to 17%	$2,750 + $3,000 per trailer	2012 to 2013	Demos	Van TT	Smartway Tractor, 53' trailer
	Full Aero Tractor & Trailer	11 to 12%	22 to 24%	$2,750 + $4,000 per trailer	2013 to 2014	—	Van TT	Smartway Tractor, 53' trailer
Tractor Trailer Aero Penalties	Flat-nose Trailer	3 to 4%	7%	-	-	~20%		Smartway Tractor
	Double trailer		-10%	-	-	-		53' single
	Fender-mounted mirrors, bug deflector, etc.	-1.5 to -3%		-	-	-		53' box trailer
	Cattle hauler, car hauler, flatbed	-5 to -13%	-10 to -30%	-	-	-		53' box trailer
Class 3-6 Box and Bucket	Roof Deflector	2 to 3%	7 to 7.5%	$500 to $800	2008	<1%		No aero add-on devices;
	Fuel Tank/Chassis fairings	0.5 to 1%	2.5 to 3%	$400 to $500	2010-2012	—		
	Box Skirts	2 to 3%	4.5 to 5%	$500 to $1,000	2010-2012	Demos		
	Cab side extension or Cab/Box Gap fairing (e.g., Nosecone)	0.5 to 1%	2.4 to 2.7%	$500 to $650	2010-2012	Demos		
	Aft Box Taper	1.5 to 3%	7.6 to 8%	$1,000	2014-2015	—		
	Cab streamlining: aero mirrors, aero bumper, streamlined shape	1 to 2%	5 to 6%	$750	2010-2012	—		
	Straight Truck aero combination package	5 to 8%	20%	$3,000 to $3,500	2015	—		
Class 2b	10% Reduction in aero drag	2 to 3%	10%	$60 to $120	Continuous	-	-	
Motor Coach-Bus	Boat Tail	4 to 6%	6.5 to 9%	$1,500 to $2,000	2012-2014	-		No aero features
	Streamlining - no cost estimate	3 to 4%	6 to 8%	$2,750	2012-2014	-		No aero features
	Motor Coach Aero Combination (boat tail + streamlining	7 to 10%	13 to 15%	$4,250 to $4,750	2014-2015	-		No aero features

Auxiliary loads: The committee stated that auxiliary loads – such as compressed air needed for the braking systems, air conditioners, power-steering systems, and the alternator to charge the vehicle's battery – can consume up to 2.5 percent of fuel, so fuel consumption reductions of 1-2.5 percent are feasible.[147] The committee suggested that electrification of these auxiliaries, mostly in hybrid vehicles, will reduce some of this loss.[148]

Rolling resistance: The committee stated that technological advances have lowered the coefficient of rolling resistance of tires by roughly 50 percent since 1990, but that further reductions are expected to be less dramatic.[149] The use of low rolling resistance tires, such as wide-based singles, show 4-11 percent reductions in fuel consumption with computer models and on-road tests, depending on terrain, weight, and choice of baseline tire.[150] The committee noted, however, that very advanced low rolling resistance tires are presently not available in tire dimensions used on many Class 3-6 vehicles, and that tires with the very lowest rolling resistance levels may not be practical for all applications,[151] which will make it very challenging to have uniformly low rolling resistance for all vehicle applications.[152]

That said, the committee noted that tire pressure monitoring, automatic inflation systems, and nitrogen inflation are all effective in avoiding wasting fuel due to underinflation and improve vehicle safety.[153] The committee recommended that since there are numerous variables that contribute to the range of results of test programs, an industry standard (SAE) protocol for measuring and reporting the coefficient of rolling resistance should be developed to aid consumer selection, similar to that proposed for passenger cars.[154]

Vehicle mass (weight): Based on results from tests and computer models, the committee found that the impact of weight on truck fuel consumption will range from 0.5-1.0 percent per 1,000 lbs on level roads to over 2 percent per 1,000 lbs on hilly terrain and for driving cycles with frequent accelerations.[155] The committee stressed that these results are primarily for Class 8 combination trucks, and that for these trucks at full weight capacity, the payload-specific fuel consumption is reduced by about 2 percent per 1,000 lbs.[156] In terms of how (and how much) weight can be reduced, the committee stated that design progress and the use of lightweight materials for major components, such as the engine, drivetrain, wheels and tires, and chassis, have been estimated to save

[147] Id., Finding 5-5.
[148] Id.
[149] Id., Finding 5-6.
[150] Id.
[151] The committee noted that tires must satisfy a range of performance criteria (besides rolling resistance, also wear, noise, traction, durability, and cost), and cited the example of tires designed for optimal mud or snow traction which typically have more void in the tread pattern as an example of a tire that generally cannot have low rolling resistance. Id. at 111-112.
[152] Id. at 112.
[153] Id. at 128, Finding 5-7.
[154] Id., Recommendation 5-2.
[155] Id., Finding 5-8.
[156] Id.

weight up to 20 percent beyond current technology – which could amount to as much as 5,000 lbs over the next decade – by the 21st Century Truck Partnership and separately by one manufacturer.[157] The committee suggested that a fuel consumption reduction of about 5 percent could be achieved.[158]

Below is a summary table of the weight reduction technologies and their costs and effectiveness considered by the committee as presented in the TIAX report.

Table II.C.7: Weight Reduction Technology Matrix

Category	Technology	FC Benefit	Cd/Crr/Wt Change	Capital cost (RPE)	Intro Year	Sales Pen.	Baseline Section No.
Tractor Trailer	WBS + aluminum wheels — benefit is included in WBS line item under tires	0 to 0.3%	100 lbs per tire	$225 per wheel + tire	2008	10%	aluminum duals
	Volume-constrained 0 to 1,000 lbs 1,000 to 2,000 lbs 2,000 to 3,000 lbs	0.4 to 0.6%	Per 1,000 lbs	$2 to $4/lb $4 to $8/lb $8 to $10/lb	Continuous	—	65K lb GVW
	Weight-constrained 0 to 1,000 lbs 1,000 to 2,000 lbs 2,000 to 3,000 lbs	2.20%	Per 1,000 lbs	$2 to $4/lb $4 to $8/lb $8 to $10/lb	Continuous	—	80K lb GVW
Refuse Hauler	0 to 1,000 lbs 1,000 to 2,000 lbs	1.4 to 2.3%	Per 1,000 lbs	$4 to $8/lb $8 to $10/lb	Continuous	—	80K lb GVW
Transit Bus	0 to 800 lbs 800 to 1,600 lbs 1,600 to 2,800 lbs	2 to 3%	Per 1,000 lbs	$2 to $4/lb $4 to $8/lb $8 to $10/lb	Continuous	—	28.5K lb GVW 4.4.3
Class 3-6 Box and Bucket	WBS + aluminum wheels -- benefit is included in WBS line item under tires	0.1% for 4 wheels	~100 lbs per tire+wheel	See WBS under tires	2008	?	steel duals
	0 to 470 lbs 470 to 940 lbs 940 to 1,650 lbs	3 to 5%	Per 1,000 lbs	$2 to $4/lb $4 to $8/lb $8 to $10/lb	Continuous	—	16.5K lb GVW
Class 2b	Weight reduction via materials substitution, up to 2%	0.6 to 0.9% per 3% saved	1 to 2%	$1 to $2/lb	2012	-	No weight reduction
	Materials substitution - Weight Reduction - 5%	0.6 to 0.9% per 3% saved	2 to 5%	$2 to $4/lb	2014	-	incremental to 2% weight
Motor Coach	0 to 1,000 lbs 1,000 to 2,000 lbs 2,000 to 3,500 lbs	0.70%	Per 1,000 lbs	$2 to $4/lb $4 to $8/lb $8 to $10/lb	Continuous	—	36K lb GVW

Idle reduction: The committee stated that there are a number of technologies and products available for reducing idle fuel use in Class 8 HD vehicles, such as automatic shut-down/start-up systems, battery-powered idle reduction systems, fuel-operated heaters (or direct-fired heaters), auxiliary power units (APUs), and truck stop electrification.[159] It is reported that up to 9 percent fuel consumption reduction is available, but it is dependent on the hotel power load factor.[160] The committee stated that it had used 5-9 percent, and TIAX had used an average of 6 percent fuel consumption reduction potential.[161]

[157] Id., Finding 5-9.
[158] Id.
[159] Id., Finding 5-10.
[160] Id.
[161] Id.

Table II.C.8: Idle Reduction Technology Matrix

Category	Technology	FC Benefit	Cd/Crr/Wt Change	Capital cost (RPE)	Intro Year	Sales Pen.	Baseline
Tractor Trailer - Long Haul	Automatic Engine Idle Management - 0.5 gal/hr, 1,500 to 2,400 hrs/yr	3%	—	$1,000 to $4,000	2008	?	1,500 to 2,400 hours per year idling; 0.8 gal/hr
	Direct fire heater - saves 0.2 to 0.3 gal/hr 500 to 800 hrs/yr	1.3 to 2.3%	—	$1,000 - $3,000	2008	?	1,500 to 2,400 hours per year idling; 0.8 gal/hr
	Battery System – 0 gal/hr, ~10 hours of life; requires off-board charging	5 to 9%	400 to 500 lbs	$3,000 to $8,000	2008	?	1,500 to 2,400 hours per year idling; 0.8 gal/hr
	APU – 0.2 to 0.3 gal/hr, 1,500 to 2,400 hrs/yr	4 to 7%	400 to 500 lbs	$6,000 to $8,000	2009	?	1,500 to 2,400 hours per year idling; 0.8 gal/hr

<u>Intelligent vehicle technologies</u>: The committee found that, in general, intelligent vehicle technologies provide fuel consumption reductions by taking advantage of knowledge of the vehicle's location, terrain in the vicinity of the vehicle, congestion, location of leading vehicles, historical traffic data, and so forth, and altering the speed of the vehicle, the route the vehicle travels, or, in the case of hybrid electric vehicles, altering the power split ratio.[162] The committee cautioned, however, that these fuel savings may not show up in any fuel consumption test, but noted that a number of the technologies, such as adaptive cruise control, predictive cruise control, and navigation and route optimization, are being applied by the trucking industry even without regulation because the owners and operators view the reduction in fuel costs as good business practice.[163] The committee stated that based on experiments to date, the electronic tow bar concept of trucks traveling closely spaced in tandem can provide significantly lower fuel consumption, 8 to 15 percent, compared with the same vehicles traveling separately.

Table II.C.9: Intelligent Vehicle Technology (IVT) Matrix

Category	Technology	FC Benefit	Cd/Crr/Wt Change	Capital cost (RPE)	Intro Year	Sales Pen.	Vocation	Baseline
Driver Management and Coaching	Route Management – telematics for congestion & weather avoidance	0 to 1%	—	$400 to $800	2010	—	Any	No route management
	Engine & Driveline Management (load-based speed control, multi-torque)	1 to 2%	—	—	2009	?	Long haul	Non-controlled engine
	Adaptive cruise control — Slows according to traffic	0 to 1%	—	$2,000 to $3,000	pre-2008	10%	Long Haul	basic cruise control
	Predictive cruise control — adjusts vehicle according to topology, conditions	1 to 2%	—	$100	2012	—	Long Haul	basic cruise control +Telematic GPS system
	Speed Governor - 60 MPH	0.4 to 0.5% per MPH	—	—	pre-2008	25 to 50%	Long Haul	70MPH speed
	Training & Feedback — driving training, sweet-spot indicator, rewards, etc	1 to 4%	—	$0 to $1,600	Continuous	25 to 50%	Long Haul	No coaching

Chapter 6 considered the costs and benefits of integrating the fuel consumption reduction technologies discussed in Chapters 4 and 5 into MD/HD vehicles. The

[162] Id. at 129, Finding 5-11.
[163] Id., Findings 5-11 and 5-12.

committee noted that while some technologies are already available in production, others are not, so reliable, peer-reviewed data on fuel-saving performance are available only for a few technologies in a few applications.[164] The committee explained that as a result, it had relied on information from a wide range of sources (including information gathered directly from manufacturers, suppliers, research labs, and major fleets), including many results that have not been duplicated by other researchers or verified over a range of duty cycles.[165] The committee also cautioned against over-reliance on unduplicated results or extrapolation to other classes of vehicles or duty cycles, and against the tendency to underestimate the problems that could emerge with pre-production technologies as they mature to commercial application.[166] The committee emphasized that extensive additional research would be needed to quantify the extent to which some technologies may be available later or at a lower level of performance than expected, and stated that regulators will need to allow for the fact that some technologies may not mature as expected.[167]

In considering technology costs, the committee discussed the fact that purchasers must weigh the cost of adding the technologies against the fuel savings that will accrue, and that as a result, many technologies may struggle to achieve market acceptance, despite the sometimes substantial fuel savings, unless driven by regulation or by higher fuel prices to push through the barriers associated with R&D and investing in new technologies.[168] The committee's methodology for evaluating the potential limits of costs and effectiveness was to group technologies into time periods based on the committee's estimate of when the technologies would be proven and available.[169]

Tractor-trailers: The committee stated that since tractor-trailer trucks have relatively high fuel consumption, very high average vehicle miles traveled, and a large share of the overall truck market, it makes sense to put a priority on fuel consumption reduction from these vehicles.[170] The committee indicated that a given percentage reduction in this vehicle category will save more fuel than a matching percent improvement in any other vehicle category, and that in fact, the potential fuel savings in tractor-trailer trucks represents about half of the total possible fuel savings in all categories of MD/HD vehicles.[171] The committee found the fuel consumption reduction potential for the tractor-trailer application in the 2015-2020 timeframe is 50.5 percent at a cost of $84,600, which results in a capital cost per percent reduction ("CCPPR") of $1,674/1 percent fuel consumption reduction.[172]

[164] Id. at 131. In presentations to NHTSA, the committee emphasized that this situation contrasts greatly with light-duty fuel consumption reducing technologies, which have been studied extensively over the last several decades, and the committee stressed that the estimates presented in the March 2010 report should be considered with that in mind.
[165] Id.
[166] Id.
[167] Id.
[168] Id.
[169] Id.
[170] Id. at 155, Finding 6-1.
[171] Id.
[172] Id., Finding 6-2.

Class 6 box and bucket trucks: The committee found that the fuel consumption reduction potential for Class 6 box and bucket trucks in the 2015-2020 timeframe is 47.1 percent for box trucks and 49.6 percent for bucket trucks.[173] The resulting cost for box trucks is $43,120 with a CCPPR of $915/1 percent fuel saved, and the cost for bucket trucks is $49.870 with a CCPPR of $1,005/1 percent fuel saved.[174]

Class 2b pickups and vans: The committee found that the fuel consumption reduction potential for the Class 2b pickup and van application in the 2015-2020 timeframe is 44.5 percent at a cost of $14,710, which results in a CCPPR of $331/1percent fuel consumption reduction.[175]

Refuse trucks: The committee found that the fuel consumption reduction potential for the refuse truck in the 2015-2020 timeframe is 38.4 percent at a cost of $50,800, which results in a CCPPR of $1,323/1 percent fuel consumption reduction.[176]

Transit buses: The committee found that the fuel consumption reduction potential for transit bus applications in the 2015-2020 timeframe is 47.8 percent at a cost of $250,400 (without subsidy), which results in a CCPPR of $5,232/1 percent fuel consumption reduction.[177]

Motor coaches: The committee found that the fuel consumption reduction potential for the motor coach application in the 2015-2020 timeframe is 32 percent at a cost of $36,350, which results in a CCPPR of $1,136/1 percent fuel consumption reduction.[178]

The committee also addressed operating and maintenance (O&M) costs, which are generally divided into two groups -- vehicle-based and driver-based -- and discussed O&M cost trends.[179] The committee identified vehicle-based O&M costs as fuel, oil, truck/trailer lease and purchase payments, repair, maintenance, tires, etc.[180] Driver-based O&M costs were identified as driver wages, benefits, and bonuses.[181] The committee found that, historically, driver pay has been the highest operating expense, but due to increases in energy costs, fuel costs have now equaled or exceeded driver pay.[182] The committee projected O&M costs for some sample technologies, but concluded that additional study is required to refine estimates of O&M costs for fuel-saving technologies

[173] Id., Finding 6-3.
[174] Id., Finding 6-3.
[175] Id., Finding 6-4.
[176] Id., Finding 6-5.
[177] Id., Finding 6-6.
[178] Id. at 156, Finding 6-7.
[179] Id. at 149.
[180] Id., Table 6-21.
[181] Id.
[182] Id.

for purposes of establishing a regulatory system, since O&M costs can be a significant portion of the overall cost of implementing these fuel-saving technologies.[183]

Overall, for the seven vehicle applications studied and summarized above, the committee presented the following summary of fuel consumption reduction potential, capital costs, and cost/benefit for the 2015-2020 timeframe:[184]

Table II.C.10: NAS Summary of Technologies for 2015-2020

Fuel Consumption Reduction, Capital Cost, and CCPPR - 2015 to 2020 Vehicle Technology							
Technology	**TT**	**Box**	**Bucket[d]**	**Refuse**	**Bus**	**Coach**	**2b**
Fuel Consumption Reduction [%]							
Aero	11.50%	6%	—	—	—	8%	3%
Engine	20%	14%	11.20%	14%	14%	20%	23%
Weight	1.25%	4%	3.20%	1%	6.25%	1.05%	0.75%
Tire	11%	3%	2.40%	2.50%	1.50%	3%	2%
Transmission	7%	4%	3.20%	4%	4%	4.50%	7.50%
Hybrid	10%	30%	40%	25%	35%	—	18%
Mgmt	6%	—	—	—	—	—	—
Idle Reduction[a]	—	—	—	—	—	—	—
Subtotal[b]	51.00%	49.40%	51.30%	40.20%	50.40%	32.50%	44.90%
Added Wt (lb)[c]	2,030	1,100	1,050	1,500	2,000	1,100	300
Adj. FC Total	**50.50%**	**47.10%**	**49.60%**	**38.40%**	**47.80%**	**32.00%**	**44.50%**
Capital Cost [$]							
Aero	$ 12,000	$ 3,250	-	-	-	$ 4,500	$ 100
Engine	$ 23,000	$ 13,000	$ 13,000	$ 14,800	$ 13,000	$ 23,000	$ 4,000
Weight	$ 13,500	$ 4,770	$ 4,770	$ 3,000	$ 15,300	$ 6,000	$ 600
Tire	$ 3,600	$ 300	$ 300	$ 300	$ 300	$ 450	$ 10
Transmission	$ 5,800	$ 1,800	$ 1,800	$ 2,700	$ 1,800	$ 2,400	$ 1,000
Hybrid	$ 25,000	$ 20,000	$ 30,000	$ 30,000	$ 220,000	—	$ 9,000
Mgmt	$ 1,700	—	—	—	—	—	—
Idle Reduction[a]	—	—	—	—	—	—	—
Total	**$ 84,600**	**$ 43,120**	**$ 49,870**	**$ 50,800**	**$ 250,400**	**$ 36,350**	**$ 14,710**
CCPPR ($/Percent Fuel Consumption Benefit)							
Aero	$ 1,043	$ 542	-	-	-	$ 563	$ 33
Engine	$ 1,150	$ 929	$ 929	$ 1,057	$ 929	$ 1,150	$ 174
Weight	$ 10,800	$ 1,193	$ 1,193	$ 3,000	$ 2,448	$ 5,714	$ 800
Tire	$ 327	$ 100	$ 100	$ 120	$ 200	$ 150	$ 5
Transmission	$ 829	$ 450	$ 450	$ 675	$ 450	$ 533	$ 133
Hybrid	$ 2,500	$ 667	$ 750	$ 1,200	$ 6,286	—	$ 500
Mgmt	$ 283	—	—	—	—	—	—
Idle Reduction[a]	—	—	—	—	—	—	—
All Strategies	**$ 1,674**	**$ 915**	**$ 1,006**	**$ 1,323**	**$ 5,232**	**$ 1,135**	**$ 331**
[a]Overnight idle reduction is assumed to be implemented as part of the hybrid package.							
[b]Does not include fuel consumption penalty associated with added weight of fuel saving technologies.							
[c]Added weight of fuel savings technologies							
[d]Assumes that 80% of fuel is used on road, and 20% is used at idle.							

[183] Id.

[184] Id. at 146, and Finding 6-8.

The committee emphasized that the results in this table were calculated assuming a 7 percent discount rate and a 10-year life, and excluded incremental operating and maintenance costs associated with the technologies.[185] Many manufacturers of MD/HD trucks, particularly Class 8 combination tractors, use much higher discount rates and much shorter vehicle life estimate in their internal cost-benefit calculations when determining whether to add fuel-saving technologies because truck buyers often do not plan to own the trucks for their full expected lifetime. The committee stressed that results would vary depending on the input assumptions used, but stated that based on these assumptions, the tractor-trailer offered the best cost benefit potential, followed by the motor coach, while the refuse hauler would cost more than twice as much per gallon of fuel saved, and other vehicle classes were even more expensive.[186] The committee recommended that NHTSA's study include an economic/payback analysis based on fuel usage by application and different fuel price scenarios, and stressed that operating and maintenance costs should be part of any study.[187]

D. Indirect Effects and Externalities (Chapter 6)

The committee explained that although direct costs and benefits are critical to understand, as the economics of technology implementation are a primary decision attribute for manufacturers, carriers, and operators, the indirect costs, benefits, effects, and externalities should also be addressed in developing a regulatory system.[188] The committee considered, at a high level, the following indirect costs and benefits, including (1) fleet turnover effects, (2) ton-miles traveled and the rebound effect, (3) vehicle class shifting by consumers, (4) environmental co-benefits and costs, (5) congestion, (6) safety impacts, (7) incremental weight effects, and (8) manufacturability and product development.[189] The committee stressed that this was not an exhaustive list of indirect effects, and encouraged the agency to assess possible indirect effects during policy development to help avoid or mitigate negative unintended consequences.[190]

<u>Fleet turnover effects</u>: The committee stated that consumer buying in anticipation of new regulations (pre-buy) and retention of older vehicles can slow the rate of fleet turnover and the rate at which regulatory standards can affect in-use fleet fuel consumption.[191] However, the committee expressed its belief that these effects will be transient and reduced to the extent that fuel consumption savings offset incremental purchase costs.[192] The committee suggested that government incentives in the form of tax credits or excise tax reductions with a sunset date could be used to help minimize

[185] Id. at 156.
[186] Id.
[187] Id. at 157, Recommendation 6-1.
[188] Id. at 149.
[189] Id.; *see also* Id. at 156, Finding 6-9.
[190] Id. at 150.
[191] Id. at 156, Finding 6-10.
[192] Id.

anticipated pre-buy/low-buy fluctuations in the future.[193] The committee emphasized that regulators must be cognizant of these potential effects and should consider regulatory mechanisms that minimize these potential distortions.[194]

Rebound effect: The "rebound effect" for MD/HD vehicles measures the increase in ton-miles shipped (or more generally, vehicle miles driven) resulting from a reduction in the cost of shipping (or more generally, driving). The committee stated that elasticity estimates vary over a wide range, and that it is not possible to calculate with a great deal of confidence what the magnitude of the rebound effect is for these vehicles.[195] However, the committee stated, a rebound effect nevertheless likely exists that will partially offset fuel consumption declines due to the adoption of new cost-effective technologies.[196] The committee emphasized that to the extent the regulation pushes beyond the private cost-effective point, the rebound effect will be reversed,[197] meaning that the costs of shipping will have increased, and will ship less freight. The committee cautioned that estimates of fuel savings from regulatory standards will be somewhat misestimated if the rebound effect is not considered.[198]

Vehicle class shifting: The committee stated that standards that differentially affect the capital and operating costs of individual vehicle classes (for example, if Class 8 trucks are regulated but not Class 6 trucks) can cause purchase of vehicles that are not optimized for particular operating conditions.[199] The committee cautioned that the complexity of truck use and the variability of duty cycles increase the probability of these unintended consequences.[200]

Environmental co-benefits: The committee stated that reduced fuel consumption through fuel efficiency technologies in MD/HD vehicles will likely reduce emissions of criteria pollutants[201] (although this also depends on the direction and magnitude of the rebound effect). Efficiency improvements achieved by improved aerodynamics, tire rolling resistance, and weight reductions will translate into lower tailpipe emissions as well.[202]

Congestion: The committee stated that to the extent that regulations alter the number of shipments and VMT, there will be some safety and congestion impacts.[203] The possible rebound effect may increase truck VMT and thus add to congestion. Further, if the regulations have performance impacts that result in slower trucks, congestion could also increase. The committee suggested that a more detailed

[193] Id.
[194] Id.
[195] Id., Finding 6-11.
[196] Id.
[197] Id.
[198] Id.
[199] Id., Finding 6-12.
[200] Id.
[201] Id., Finding 6-13.
[202] Id.
[203] Id., Finding 6-14.

assessment of these impacts would be needed based on the type of regulation put forward by NHTSA.[204]

Safety: The committee stated that there are potential safety issues associated with MD/HD fuel efficiency standards.[205] First, new technologies may have specific safety issues associated with them – such as the need for operators, service mechanics, and emergency personnel to be educated about high-voltage electrical equipment in hybrid trucks, or aerodynamic fairings that may detach on the road.[206] Second, the rebound effect may increase overall truck traffic on the road, thereby leading to potentially higher incidences of accidents.[207] Third, some technologies and/or approaches to improving fuel efficiency may actually lead to a safer highway system, such as speed reductions, improved driver training, and use of side fairings that may reduce hazards to other vehicles in inclement weather.[208] Fourth, if new technologies diminish the performance of vehicles (e.g., by decreasing acceleration times), negative safety impacts could occur.[209] And finally, if new technologies or regulations have the effect of increasing payload capacity for trucks, fewer trucks may be in operation, potentially resulting in safety benefits.[210] The committee stated that a more detailed assessment of all these safety aspects would be needed based on the type of regulation that NHTSA ultimately puts forth.[211]

Incremental weight effects: The committee stated that some fuel efficiency reduction technologies will add weight to vehicles and push those vehicles over Federal threshold weights, thereby triggering new operational conditions, and affecting, in turn, vehicle purchase decisions.[212] The committee indicated that more research is needed to assess the significance of this potential impact.[213] The committee also stated that, on the other hand, some fuel efficiency reduction technologies will reduce cargo capacity for truck models that are currently "weighed out" (i.e., adding weight to trucks that already hit the maximum weight allowed on highways and bridges will mean that more trucks will be needed to transport the same payload to enable each truck to stay under current weight limits).[214] The committee indicated that more research is also needed to assess the significance of this potential impact.[215]

Manufacturability and product development: The committee stated that it found no current studies or analyses suggesting that manufacturability was a major barrier to the integration of gas/diesel engine, hybrid, aero, tire, or other technologies in the vehicle

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[204] Id.
[205] Id., Finding 6-15.
[206] Id. at 153.
[207] Id.
[208] Id.
[209] Id.
[210] Id.
[211] Id. at 154.
[212] Id. at 156-157, Finding 6-16.
[213] Id. at 157.
[214] Id., Finding 6-17.
[215] Id.

manufacturing process.[216] However, it cautioned that there may be challenges with integrating new technologies into manufacturers' product development processes, and that sufficient time would be needed for design and validation, customer acceptance, testing, and compliance strategy development.[217]

E. Alternative Approaches (Outside NHTSA Authority) to Reducing Fuel Consumption From MD/HD Vehicles (Chapter 7)

Besides fuel efficiency-improving technologies, the committee considered a number of alternative approaches to improving fuel efficiency, including (1) changing fuel price signals through fuel taxes or cap-and-trade systems (specifically, their implications for the trucking industry); (2) technology-specific mandates and subsidies; (3) alternative or complementary regulations such as emissions limits, size and weight limits, and mandatory speed limits; and (4) other complementary approaches such as intelligent transportation systems, construction of exclusive truck lanes, congestion pricing, driver training, and intermodal operations.[218] The committee stated that these different approaches could either be in addition to or in place of fuel efficiency standards, but cautioned that all of the approaches are complex and would require a great deal more study, particularly with respect to the impact they might have on actual fuel efficiency improvements.[219] Nevertheless, the committee stated that any government action taken to reduce fuel consumption in the trucking sector should consider these alternatives.[220]

Changing fuel price signals – fuel taxes: The committee stated that fuel taxes offer a transparent and efficient method for internalizing the potential societal costs of climate change and oil security and for reducing fuel consumption.[221] The committee noted that fuel taxes operate to make fuel-saving technologies more attractive and provide incentives for saving fuel in operations, while involving fewer unintended consequences than standards.[222] The committee suggested that fuel taxes can be designed to lessen the uncertainties facing the trucking sector and to provide a market signal for investments in fuel-saving technology.[223] The committee strongly recommended that Congress consider fuel taxes as an alternative to mandating fuel efficiency standards for MD/HD vehicles, although it recognized the political difficulty associated with doing so.[224]

Changing fuel price signals – cap-and-trade: The committee stated that a cap-and-trade system for carbon emissions would provide market signals for truckers to adopt fuel-saving technology and operations, but that the market signal would be more

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[216] Id., Finding 6-18.
[217] Id.
[218] Id. at 159.
[219] Id.
[220] Id. at 176, Finding 7-1.
[221] Id., Finding 7-2.
[222] Id.
[223] Id., Finding 7-3.
[224] Id., Recommendation 7-1.

uncertain and volatile than would be provided by fuel taxes.[225] If the cap-and-trade system limited total CO_2 emissions by primary energy producers, the committee found that it would have implications for the trucking sector, such that regulators would not need to develop standards for CO_2 emissions that apply to specific trucks and trucking operations, and could thus avoid the complexity of different classes and duty cycles of trucks.[226] However, the committee cautioned, the cap-and-trade system would likely involve new administrative burdens for monitoring emissions from the primary producers and policing the system.[227]

Technology-specific mandates and subsidies: The committee stated that methods to encourage the adoption of specific technologies, whether mandates or subsidies, are best utilized when options are limited and the compatibility with truck usage and duty cycle are clear.[228] However, the committee found that when there are several fuel-saving options and complex truck operating conditions, performance standards are likely to be superior to specific technology requirements.[229]

One primary example of a technology-specific mandate is the California Air Resources Board (CARB) adoption of the EPA SmartWay program. Under this scenario, CARB requires operators in California either to retrofit current vehicles with SmartWay certified technologies, or to purchase SmartWay certified vehicles when moving freight. Technologies adopted under this program include aerodynamic drag reducing technologies and low rolling resistance tires, among others.

Alternative/complementary regulations – vehicle size and weight limits: The committee found that increasing vehicle size and weight limits offered potential significant fuel savings for the entire tractor-trailer combination truck fleet – up to 15 percent or more – but cautioned that attempting this through regulation would need to be weighed against the increased costs of road repair.[230] The committee stated that in order to accomplish this, the government would have to (1) change regulatory limits that currently restrict vehicle weigh to 80,000 lbs and that freeze longer combination vehicle (LCV) operations on the Federal Interstate System; (2) establish a regulatory structure that assures safety and compatibility with the infrastructure;[231] and (3) consider the necessary changes that would be required to permit reasonable access of LCVs to vehicle breakdown yards and major shipping facilities in close proximity to the interstate.[232] The committee recommended that Congress should give serious consideration to liberalizing weight and size restrictions and should consider how the potential fuel savings and other

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[225] Id., Finding 7-4.
[226] Id., Finding 7-5.
[227] Id. at 177.
[228] Id., Finding 7-6.
[229] Id., Finding 7-7.
[230] Id., Finding 7-8.
[231] The committee indicated that one possible regulatory structure has been proposed by the TRB Committee on Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles, Special Report 267. Id., Finding 7-8.
[232] Id.

benefits of such liberalization can be realized in a way that maintains safety and minimizes the cost of potential infrastructure changes.[233]

Alternative/complementary regulations – mandatory speed limits: The committee stated that mandatory road-speed-governor settings have long been used in Europe, and that most large U.S. fleets already use speed governors and they could be implemented more generally in the U.S. market.[234] The committee found that the benefit of these governors is only significant for vehicles that spend a large amount of time at high-speed cruise, where one might expect roughly 1 percent fuel savings for each mph reduced (such that reducing speeds from 65 mph to 60 mph may lead to 3 to 5 percent fuel savings).[235] However, the committee cautioned that road-speed governors have a number of disadvantages and potential unintended consequences, including, among other things, that trips will take longer, which might lead to more congestion/accidents/etc., and that tampering could become a significant issue.[236]

Other complementary approaches – intelligent transportation systems: The committee stated that intelligent transportation systems enable more efficient use of the existing roadway system by improving traffic flow and reducing/avoiding congestion, which results in a reduction of large variations in speed, idle time, and periods of high acceleration, which have a considerable impact on fuel economy.[237] The committee found that many intelligent transportation system (ITS) applications are now being tested or deployed throughout the country, and that although the cost of deployment is considerable, it may allow deferment or constitute an alternative to expanding the existing roadway system.[238]

Other complementary approaches – construction of exclusive use truck lanes: The committee explored various concepts associated with Truck Exclusive highway lanes. In some cases, exclusive lanes could complement, or accelerate, the implementation of the Intelligent Highway Systems. They can also provide an opportunity to upgrade current, aging highway systems to handle more weight and future traffic. The committee noted that some metropolitan areas are currently evaluating the strategy as a preferred alternative to adding more lanes to existing highway systems.

Major advantages to constructing exclusive-use truck lanes include greater efficiency in freight movement, as well as potentially improved safety, due to the homogeneity of the vehicles on both the truck exclusive lanes and the light-duty designated lanes. However, the committee cautioned that such construction could be expensive and require continued maintenance along with unproven social costs.[239]

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233 Id., Recommendation 7-2.
234 Id., Finding 7-9.
235 Id.
236 Id., *see also* 166-168.
237 Id. at 177, Finding 7-10.
238 Id.
239 Id.

Other complementary approaches – congestion pricing: The committee found that congestion pricing offers several potential benefits, namely that reduced congestion increases overall efficiency in the freight delivery system.[240] The committee suggested fuel savings on the order of 0.1-7.7 percent based on the examples it considered.[241]

Other complementary approaches – driver training: The committee stated that there are significant opportunities for savings in fuel, equipment, maintenance, and labor when drivers are trained properly, and found that this could be one of the cheapest and best ways to reduce fuel consumption and improve productivity of the trucking sector.[242] The committee suggested that driver training could lead to potential fuel savings of roughly 2-17 percent based on the examples it considered.[243] The committee recommended that the Federal government should encourage and incentivize the dissemination of information related to the relationship between driving behavior and fuel savings, as by establishing a curriculum and process for certifying fuel-saving driving techniques as part of commercial driver license (CDL) certification, and regularly evaluating the effects of such a curriculum.[244] Some of the examples that the committee gave of driver behavior that can affect MHDV fuel consumption include speed fluctuation management, shift optimization and skipping gears, maintenance, clutch control and others that are listed in the report.[245]

Other complementary approaches – intermodal transport: The committee found that intermodal transport offers significant environmental and energy advantages compared to trucking alone on an individual cargo movement basis.[246] Because rail and ship are significantly less energy-intensive than trucks, incentivizing the movement of goods from truck to rail or ship is one way to improve the overall efficiency of the freight transportation system.[247] However, the committee cautioned that the system-wide opportunities for intermodal transport are currently limited based on existing infrastructure, customer demands, cargo compatibility, and economic feasibility.[248]

F. Approaches to Fuel Economy and Regulations (Chapter 8)

The committee examined the broad variations in medium and heavy duty vehicles and explained how the complex nature of trucks influences regulatory options.[249] Today, while there is an existing heavy-duty vehicle exhaust emissions program with its own regulated entities (engine manufacturers), test method (engine dynamometer), and test

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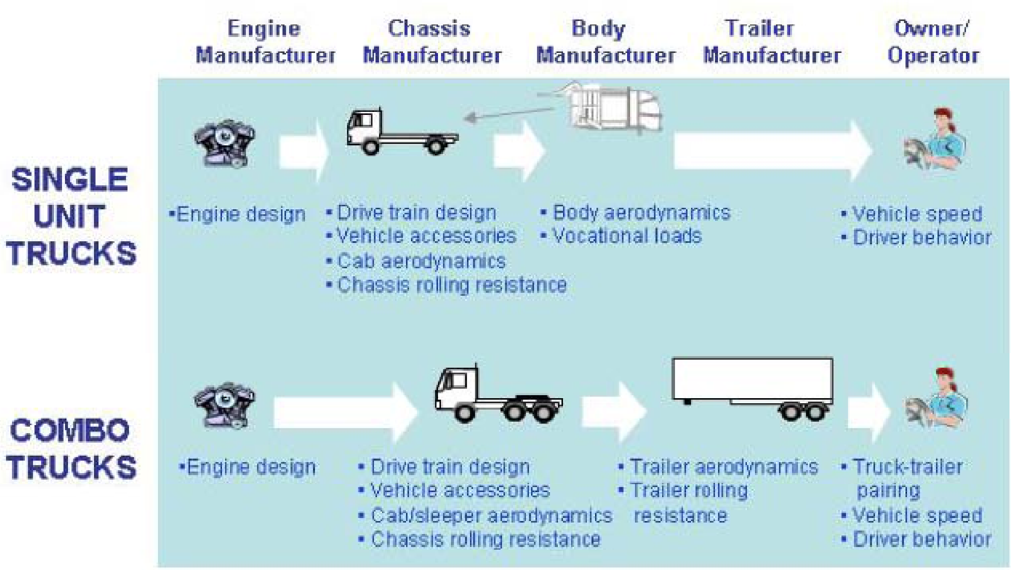
[240] Id., Finding 7-11.
[241] Id.
[242] Id., Finding 7-12.
[243] Id.
[244] Id., Recommendation 7-3. We note that initial efforts are underway to bring the attention of this finding to the Federal Motor Carrier Safety Administration Entry-Level Driver Training Team, in order to explore and evaluate additions to the training program in regard to fuel-saving operating practices.
[245] Id. at 174.
[246] Id. at 177, Finding 7-13.
[247] Id. at 175.
[248] Id. at 176.
[249] Id. at 179.

cycles (Federal Test Procedure [FTP], Supplemental Emissions Test [SET], Ramped Modal Cycle [RMC], and in-use tests), there are factors associated with the U.S. vehicle market that make fuel consumption regulations more difficult and complicated than the design of fuel economy standards for passenger vehicles.[250] The committee listed three main challenges to be considered:

(1) The heavy-duty vehicle market is extremely diverse, with a wide range of vehicle types, sizes, and duty cycles.
(2) Heavy-duty vehicle manufacturing is driven by customer specifications, which often leads to a far greater variety of pairings between major components (e.g., engine, transmission, chassis, axles, wheels, body shape).
(3) Unlike passenger vehicles, vehicle manufacturing is often split between two different manufacturers: the producer of the chassis and a second manufacturer that purchases the chassis, adds a body and special equipment, and ultimately sells the vehicle to the consumer (see the figure below). The exceptions are pickup trucks and truck tractors, which are completely assembled by the final manufacturer.[251]

Figure II.F.1 -- NAS Report Figure 8-1: Shared responsibility for major elements that affect heavy-duty vehicle fuel efficiency (source: NESCCAF/ICCT (2009])



[250] Id.
[251] Id.

As an approach to overcome these challenges, the committee stated that the purpose and structure of NHTSA's regulatory program should be as follows:

(1) Generate cost-effective reductions in fuel consumption from MD/HD vehicles, maximizing the savings of fuel at a justifiable cost imposed on the industry and society;
(2) Accelerate the research, development, and market penetration of new and existing energy saving technologies;
(3) Reduce the amount of energy consumed per movement of freight or passengers;
(4) Build on existing market incentives and company practices to lower fuel consumption; and
(5) Minimize additional administrative burden upon the regulated industry.[252]

To examine these issues more carefully, the committee considered the following major technical and policy questions:

(1) Regulated vehicle types – what types of vehicles should be regulated?
(2) Regulated parties – who should the regulated parties be?
(3) Metrics for fuel consumption – what metric should be used to measure performance?
(4) Methods for certification and compliance – what methods will be used to determine compliance and overall program effectiveness?
(5) Regulatory model.[253]

The committee's recommendations with respect to each of these questions are as follows:

Regulated vehicle types: The committee stated that while it may seem expedient to initially focus on those classes of vehicles with the largest fuel consumption (i.e., Class 8, Class 6, and Class 2b, which together account for approximately 90 percent of fuel consumption of MD/HD vehicles), the committee believes that selectively regulating only certain vehicle classes would lead to very serious unintended consequences and would compromise the intent of the regulation.[254] The table below shows the distribution of mileage and fuel consumption for different vehicle classifications. The committee suggested, however, that within vehicle classes, there may be certain subclasses of vehicles (e.g., fire trucks) that could be exempt from the regulation without creating market distortions.[255]

[252] Id.
[253] Id. at 179-180.
[254] Id. at 189, Finding 8-1.
[255] Id.

Table II.F.1 -- NAS Report Table 8-1: Mileage and Fuel Consumption By Vehicle Weight Class

U.S. Medium and Heavy Duty Vehicle Population, Mileage and Fuel Use by Weight Class						
Vehicle Size	Population [millions]	Annual Miles [million miles]	Annual Fuel Use [million gallons]	% of Population	% of Annual Miles	% of Fuel Use
Class 2B	5.800	76,700	5,500	52.8%	35.1%	19.3%
Class 3	0.691	9,744	928	6.3%	4.5%	3.3%
Class 4	0.291	4,493	529	2.6%	2.1%	1.9%
Class 5	0.166	1,939	245	1.5%	0.9%	0.9%
Class 6	1.710	21,662	3,095	15.6%	9.9%	10.9%
Class 7	0.180	5,521	863	1.6%	2.5%	3.0%
Class 8	2.154	98,522	17,284	19.6%	45.1%	60.8%
TOTAL	10.992	218,580	28,444	100%	100%	100%

SOURCE: Class 3 - 8 - U.S. Department of Commerce, Bureau of the Census, 2002 Vehicle Inventory and Use Survey; Class 2B - Davis, S.C. and L.F. Truett, Investigation of Class 2b Trucks (Vehicles of 8,500 to 10,000 lbs GVWR), ORNL/TM-2002/49, March 2002, Table 16. Class 3 - 8, 2002 Population; Class 2b, 2000 population

<u>Regulated parties</u>: The committee offered two principle considerations that should be evaluated when seeking to determine the most effective point of regulation.[256] First, the number of regulated entities must be a manageable number (in the tens rather than the hundreds) of parties to limit compliance and administrative burdens.[257] And second, the regulation must affect the corporate parties with the greatest control and authority over vehicle design and over components that offer the potential for substantial reductions in fuel consumption.[258] The committee noted that large OEMs with significant engineering capability design and manufacture almost all Class 2b, 3, and 8b vehicles. Twelve major corporations control the majority of production of commercial trucks. For example, Class 8 trucks (tractors and straight) are primarily produced by four companies (Daimler AG, Volvo, PACCAR, and Navistar) that account for more than 90 percent of U.S. truck registrations, while small companies with limited engineering resources make a significant percentage of vehicles in Classes 4 through 8a, although in many cases they buy the complete chassis from larger OEMs.[259] Class 2b to Class 4 small heavy-duty vehicles are dominated by the Big 3 U.S. auto manufacturers with 89 percent of registrations.[260]

[256] Id. at 182.
[257] Id.
[258] Id.
[259] Id.
[260] Id.

Table II.F.2 -- NAS Report Table 2-2: Product Ranges of U.S. Heavy-Duty Vehicle Manufacturers (source: Bradley and Associates[261] (2009, Figure 2.4])

STRAIGHT TRUCKS/CHASSIS		COMBINATION TRUCKS	
Class 6	**Class 8**	**Tractors**	**Trailers**
Daimler Trucks NA *Freightliner Custom Chassis* *Sterling Truck* Navistar Intl. *International Trucks* *Workhorse Custom Chassis* General Motors *Chevrolet* GMC Ford Isuzu Hino Motors Mitsubishi Fuso Paccar *Kenworth* UD Trucks	General Motors *Chevrolet* Daimler Trucks NA *Freightliner* *Sterling Truck* *Western Star* Navistar Intl. *International Trucks* Paccar *Kenworth* *Peterbuilt* Volvo *Mack*	Daimler Trucks NA *Freightliner* *Sterling Truck* *Western Star* Navistar Intl. *International Trucks* Paccar *Kenworth* *Peterbuilt* Volvo *Mack*	Fontaine Trailer Great Dane Hyundai Stoughton Trailers Strick Corporation Trailmobile Corporation Transcraft Corporation Utility Trailer Manufacturing Vanguard National Trailer Corp. Wabash National Corporation

VOCATIONAL TRUCK/BODY MANUFACTURERS[1]		
Refuse Trucks		*School Buses*
Amrep	Kann Manufacturing Corp.	Blue Bird Corporation
Autocar	Loadmaster	Collins Bus Corporation
Bridgeport Truck Manuf.	Mack Trucks	*Corbeil Bus Corporation*
Crane Carrier	McNeilus Companies, Inc.	*Mid Bus Corporation*
Dempster Equipment Co.	Oshkosh	Daimler Trucks NA
Leach	Pak-Mor Manufacturing	*Thomas Built Buses*
Haul-all Equipment Ltd.	Scranton Manufacturing Co.	Girandin Minibus
Heil Environmental Ltd.	Sterling Truck	Navistar International
Ingold's Hico, Inc.	Wayne Engineering Corp.	*IC Bus*[2]

Companies inset in *italics* are subsidiaries of the company listed above them.

[1] Example only. Other types of vocational trucks are built by different manufacturers. Many of these companies use chassis manufactured by the Truck/Chassis manufacturers.

[2] All Navistar school buses are now sold under the IC Bus brand. Navistar previously sold buses under the International and AmTran brands.

The committee emphasized that regulators will need to take into account the limitations of these smaller companies.[262] The committee also noted that commercial trailers are produced by a separate group of about 12 major manufacturers that are not associated

[261] Available at Docket No. NHTSA-2010-0079.

[262] Id. at 189, Finding 8-2.

with truck manufacturers.[263] The committee stated that trailers represent an important opportunity for fuel consumption reduction, and can benefit from improvements in aerodynamics and tires.[264]

The committee recommended that NHTSA's regulatory system focus on the final stage vehicle manufacturers, since they have the greatest control over the design of the vehicle and its major subsystems that affect fuel consumption.[265] The committee stated that component manufacturers would have to provide consistent component performance data, and emphasized that as the components are generally tested at this time, there is a need for a standardized test protocol and safeguards for the confidentiality of the data and information.[266] The committee indicated that it may be necessary for the vehicle manufacturers to provide the same level of data to the tier suppliers of the engines, transmissions, after-treatment, and hybrid systems.[267]

The committee further recommended that NHTSA separately regulate trailer manufacturers to promote more fuel-efficient trailers, including integration of the trailer design with the tractor for improved aerodynamic performance, lower tare weight, and a requirement for low rolling resistance tires.[268]

<u>Fuel consumption performance metrics</u>: The committee developed several advisory principles for itself to structure its thinking about metrics, given the complexity of HD vehicles and the high degree of specialization for different tasks that they perform:

- First, the metric should incentivize subcomponent and total vehicle development;
- Second, the metric should relate to the transport task or vehicle vocation;
- Third, the metric should encourage energy conservation for a given task; and
- Fourth, the metric should be based on energy or fuel consumption – e.g., equivalent diesel gallons/cargo ton-mile.[269]

The committee supported a performance-based metric rather than an equipment specification regulation as a better way to address the advisory principles identified.[270]

Thus, the committee stated that since the primary social benefit of the MD/HD vehicle sector is the efficient and reliable movement of freight, movement of purpose-built integrated equipment or performance of a task, it is necessary to establish a metric that includes a factor for the work performed (e.g., gallons per cargo ton-mile rather than simply gallons per mile) to ensure that the regulatory instrument meets societal goals.[271] The committee suggested that choosing a metric associated with the movement of freight

[263] Id., Finding 8-3.
[264] Id.
[265] Id., Recommendation 8-1.
[266] Id.
[267] Id.
[268] Id., Recommendation 8-2.
[269] Id. at 183.
[270] Id.
[271] Id. at 189, Finding 8-4.

will promote improvements that increase the amount of cargo that can be carried per unit of fuel consumed, and thus provide a means of quantifying the benefits of more productive vehicles that move the same amount of freight with fewer trips and less miles, such as LCVs.[272] However, the committee emphasized that setting a metric based exclusively on gallons per cargo ton-mile may not adequately address light-density freight that is limited by volume.[273] Thus, the committee recommended that NHTSA should establish fuel consumption metrics tied to the task associated with a particular type of MD/HD vehicle, and set targets based on potential improvements in vehicle efficiency and vehicle or trailer changes to increase cargo-carrying capacity.[274] The committee further recommended that NHTSA should determine whether a system of standards for full but lightly loaded ("cubed out") vehicles can be developed using only the LSFC metric, or whether these vehicles need a different metric to measure fuel efficiency properly without compromising the design of the vehicles.[275]

Methods for certification and compliance: The committee stated that regulating the total vehicle fuel consumption of MD/HD vehicles will be a formidable task due to the complexity of the fleet, the various work tasks performed, and the variations in fuel efficiency technologies within given classes, including vehicles of the same model and manufacturer.[276] The committee emphasized that a certification test method must be highly accurate, repeatable, and identical to the in-use compliance tests, as is the case with current regulation of light-duty vehicles tested on a chassis dynamometer, and for heavy-duty engine emission standards tested on engine dynamometers.[277]

The committee stated that using the process and results from existing engine dynamometer testing for criteria emissions to certify fuel economy standards for MD/HD vehicles would build on prove, accurate, and repeatable methods, and put less additional administrative burden on the industry.[278] However, the committee cautioned that to account for the fuel consumption benefits of hybrid powertrains and transmission technology, the present engine-only tests for emissions certification will need to be augmented with other powertrain components added to the engine test cell, either as real hardware or as simulated components.[279] Additionally, the vehicle attributes (aero, tires, mass) would need to be accounted for, perhaps by using vehicle-specific prescribed loads (via models) in the test cycle, which the committee stated would require close cooperation among component manufacturers and vehicle manufacturers.[280]

The committee noted that since there is currently no established Federal test method for HD vehicle fuel consumption, either empirical testing (whether at the component level or up to the whole vehicle level) or simulation modeling or both could

[272] Id., Finding 8-5.
[273] Id., Finding 8-6.
[274] Id, Recommendation 8-3.
[275] Id.
[276] Id. at 190, Finding 8-7.
[277] Id., Finding 8-8.
[278] Id., Finding 8-9.
[279] Id.
[280] Id.

be used for the characterization and certification of regulated equipment.[281] The committee cautioned that each approach involves uncertainties that can affect certification and compliance, and stressed the need for a pilot regulation program to examine the potential for these effects.[282]

The committee also noted that significant segments of the MD/HD vehicle purchasing process are highly consumer-driven, with many engine, transmission, and drive axle choice combinations resulting in a wide array of completed vehicles for a given vehicle model.[283] The committee stressed that from a regulatory standpoint, the use of expensive and time-consuming chassis testing on each distinct vehicle variation is impractical.[284] However, the committee suggested that by knowing the performance of major subcomponents on fuel consumption, it may be practical to demonstrate compliance certification with vehicle standards by aggregating the subcomponents into a specified virtual vehicle for computers to evaluate fuel consumption of the completed vehicle.[285]

The committee stated that further research will be required to underpin the protocol used to measure key input parameters, such as tire rolling resistance and aerodynamic drag forces, and to ensure the robustness of simulations for evaluating vehicle fuel consumption.[286] However, the committee stated, once determined, these major components may be assembled through simulation to represent a whole-vehicle system, and models benchmarked to reliable data may be used to extend the prediction to a variety of vehicle types, by changing bodies (aerodynamic measures), tires, and operating weights associated with the powertrains.[287]

Thus, the committee recommended that the agency consider the use of simulation modeling with component test data and additional tested inputs from powertrain tests as a way of lowering cost and administrative burdens yet achieving needed accuracy of results.[288] The committee stated that this is similar to the approach taken in Japan, but different in that the program would represent all of the parameters of the vehicle (powertrain, aerodynamics, and tires) and relate fuel consumption to the vehicle task.[289] The committee further recommended that the combined vehicle simulation/component testing approach be supplemented with tests of complete vehicles for audit purposes.[290]

Finally, the committee stressed that the agency must begin immediately to develop its regulatory approach using the findings and recommendations in the NAS

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[281] Id., Finding 8-10.
[282] Id.
[283] Id., Finding 8-11.
[284] Id.
[285] Id.
[286] Id., Finding 8-12.
[287] Id.
[288] Id., Recommendation 8-4.
[289] Id.
[290] Id.

Report, because significant engineering work is needed to produce an approach that results in fuel efficiency standards that are cost-effective and that accurately represent the effects of fuel consumption-reducing technologies.[291] The committee emphasized that the regulations should fit into the engineering and development cycle of the industry and provide meaningful data to vehicle purchasers.

To that end, the committee made two recommendations:

(1) Congress should appropriate money and NHTSA should implement as soon as possible a major engineering contract that would analyze several actual vehicles covering several applications and develop an approach to component testing data in conjunction with vehicle simulation modeling to arrive at LSFC data for these vehicles.[292] The committee stated that the actual vehicles should also be tested by appropriate full-scale test procedures to confirm the actual LSFC values and the reductions measured with fuel consumption reduction technologies as compared to the more cost-effective fleet certification approach.
(2) The committee recommended that NHTSA should conduct a pilot program to "test drive" the certification process and validate the regulatory instrument proof of concept. The committee stated that the pilot program should have the following elements:
    a. NHTSA should gain experience with certification testing, data gathering, compiling, and reporting. The committee stressed that there needs to be a concerted effort to determine the accuracy and repeatability of all the test methods and simulation strategies that will be used with any proposed regulatory standards, as well as a willingness to fix issues that are found.
    b. NHTSA should gather data on fuel consumption from several representative fleets of vehicles. The committee stated that this should continue to provide a real-world check on the effectiveness of the regulatory design on the fuel consumption of trucking fleets in various parts of the marketplace and various regions of the country.[293]

The committee gave several presentations to NHTSA and to other government agencies summarizing its findings and recommendations,[294] often emphasizing these final two recommendations over all the others. Given the vastness of the regulatory undertaking and the lack of data to inform the development of a MD/HD fuel efficiency program, compared to the light-duty fuel economy program, the committee strongly encouraged NHTSA to consider these final two recommendations carefully.

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[291] Id., Finding 8-13.
[292] Id., Recommendation 8-5.
[293] Id. at 190-191, Recommendation 8-6.
[294] These presentations are available in the docket for NHTSA's rulemaking, NHTSA-2010-0079, which can be accessed at http://www.regulations.gov.

III. NHTSA study

As discussed above, Congress directed NHTSA to conduct a study, in consultation with DOE and EPA, not later than one year after NAS published its report to examine the fuel efficiency of MD/HD vehicles and determine (1) appropriate test procedures and methodologies for measuring MD/HD vehicle fuel efficiency; (2) appropriate metrics for MD/HD vehicle fuel efficiency (considering, among other things, the work they do and the types of operations in which they are used); (3) the range of factors that affect MD/HD vehicle fuel efficiency; and (4) other factors and conditions that could have an impact on a MD/HD fuel efficiency improvement program.

The sections below explain NHTSA's methodology for conducting the study and examine each of these charges in detail, drawing from the findings and recommendations of the March 2010 NAS Report as well as from work done by NHTSA and EPA in preparation for the Notice of Proposed Rulemaking (NPRM) issued concurrently with this report.

A. How did NHTSA conduct its study?

As the March 2010 NAS Report noted, relatively little information on MD/HD fuel efficiency exists, at least as compared to the available information for the light-duty vehicle sector that has been accruing since the 1970s. To develop this study, NHTSA carefully considered the findings of the NAS Report and consulted with EPA (and to the extent possible, DOE) as to appropriate features of a regulatory system for MD/HD vehicles in the context of this first phase of the HD National Program. As mentioned above, this study was also informed by work done by EPA and NHTSA in preparation for the NPRM that is being issued concurrently with this report.

B. What test procedures and methodologies are appropriate for measuring the fuel efficiency of MD/HD vehicles?

Test procedures and measurement methodologies are important to a MD/HD fuel efficiency improvement program because they determine the ability of a regulated entity to comply with the standards that the agency sets – they represent the literal test that the regulated entity must pass in order to be certified to sell vehicles, to avoid paying fines, and so forth, and the manner in which the regulated entity takes the test. As such, they must be consistent, repeatable, accurate, and fair. Additionally, test procedures and measurement methodologies are important because they influence the amount of real-world fuel consumption improvement that is achieved by the regulatory program. The regulated industry will design products in order to improve fuel consumption as it is measured using the regulatory test procedures and measurement methodologies. In order to achieve improved fuel consumption in the real world, it will be important to assure that product changes that improve fuel consumption in regulatory tests also improve consumption in the real world. The test procedures and measurement methods themselves, must promote the development of products that improve real-world fuel consumption.

1. What did NAS recommend?

For overall test procedures, the committee noted that since there is currently no established Federal test method for HD vehicle fuel consumption, either empirical testing (whether at the component level or up to the whole vehicle level) or simulation modeling or both could be used for the characterization and certification of regulated equipment.[295] The committee cautioned that each approach involves uncertainties that can affect certification and compliance, and stressed the need for a pilot regulation program to examine the potential for these effects.[296]

As discussed above, the NAS committee emphasized that a certification test method must be highly accurate, repeatable, and identical to the in-use compliance tests, as is the case with current regulation of light-duty vehicles tested on a chassis dynamometer, and for heavy-duty engine emission standards tested on engine dynamometers.[297] The committee's fundamental recommendation, however, was that physical chassis dynamometer testing was impractical for the MD/HD fleet, given the wide variations in intended function (and thus, technology content) between classes and between vehicles within classes, and even between vehicles that are nominally the same model. The results from testing any given vehicle would not likely be applicable to enough other vehicles to make them useful for compliance/certification purposes. The committee did not directly recommend the use of engine dynamometer testing for compliance purposes because the committee was recommending complete-vehicle standards rather than separate engine and vehicle standards,[298] although the committee suggested that engine dynamometer testing could be a part of a complete-vehicle testing protocol.

Thus, because dynamometer testing is impractical, the committee suggested that computer simulation of MD/HD vehicles is an effective way to predict fuel consumption reductions considering the additional variables in a hybrid vehicle system, but expressed concern that such systems are not standardized, leading to a wide variety of results and unpredictability.[299] The committee recommended that NHTSA should support the formation of an expert working group charged with evaluating available consumer

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[295] March 2010 NAS Report, at 190, Finding 8-10.
[296] Id.
[297] Id., Finding 8-8.
[298] The committee did state, as discussed above, that using the process and results from existing engine dynamometer testing for criteria emissions to certify fuel economy standards for MD/HD vehicles would build on prove, accurate, and repeatable methods, and put less additional administrative burden on the industry, but the committee cautioned that (for purposes of complete-vehicle standards) the present engine-only tests would need to be augmented, either through real hardware or through simulation, to address vehicle attributes such as powertrain, aero, tires, mass, etc.
[299] Id. at 87, Finding 4-10.

simulation tools for predicting fuel consumption reduction in MD/HD vehicles and developing standards for further use and integration of these simulation tools.[300]

Additionally, the committee stated that further research will be required to underpin the protocol used to measure key input parameters, such as tire rolling resistance and aerodynamic drag forces, and to ensure the robustness of simulations for evaluating vehicle fuel consumption.[301] However, the committee stated, once determined, it may be practical to assemble these major components through simulation to represent a virtual whole-vehicle system, and models benchmarked to reliable data may be used to extend the prediction to a variety of vehicle types, by changing bodies (aerodynamic measures), tires, and operating weights associated with the powertrains.[302]

Thus, the committee recommended that the agency consider the use of simulation modeling with component test data and additional tested inputs from powertrain tests as a way of lowering cost and administrative burdens yet achieving needed accuracy of results.[303] The committee stated that this is similar to the approach taken in Japan, but different in that the program would represent all of the parameters of the vehicle (powertrain, aerodynamics, and tires) and relate fuel consumption to the vehicle task.[304] The committee further recommended that the combined vehicle simulation/component testing approach be supplemented with tests of complete vehicles for audit purposes.[305]

For any vehicle fuel consumption test or simulation, the committee stressed that the choice of test cycle is critical.[306] The committee stated that test cycles selected for regulatory use will need to reflect real-world duty cycles to the extent possible, and that parameters of importance include maximum speed, average speed, speed fluctuation, number of stops, and amount of idling.[307] The committee emphasized that it will not be possible to faithfully reproduce the duty cycle to be experienced by every vehicle, so similar applications will need to be represented by one or a few duty cycles for regulatory purposes.[308]

For specific component test procedures, the committee offered recommendations for measuring aerodynamic drag and tire rolling resistance. With regard to aerodynamic drag, the committee stated that coast-down testing can be used to define a vehicle's rolling resistance and characteristic aerodynamic drag, but the committee stressed that it must be well-regulated and that it can be imprecise and complicated by prevailing winds, vehicle mass, and the nature of the road surface.[309] The committee stated that wind tunnel testing is the only accurate method to measure aerodynamic drag force directly,

[300] Id., Recommendation 4-4.
[301] Id. at 190, Finding 8-12.
[302] Id.
[303] Id., Recommendation 8-4.
[304] Id.
[305] Id.
[306] Id. at 187.
[307] Id.
[308] Id.
[309] Id. at 29.

because it can directly account for yaw (sideways) forces.[310] When possibly combined with CFD codes, which perform millions of computer calculations to simulate the interaction of fluids and gases with the complex exterior surfaces of the vehicle, the committee suggested that a wind tunnel approach was preferable for measuring aerodynamic drag.[311] For greater certainty, however, the committee suggested that the agency request the SAE's Truck and Bus Aerodynamic and Fuel Economy Committee to examine this issue in greater depth and provide recommendations with regard to the validation, accuracy, and precision of different measurement methods for aero drag, including SAE J1321, EPA's modification of SAE J1321, coast down, wind tunnel, CFD, and full-truck computer simulation testing.[312]

Thus, the committee recommended that regulators require aerodynamic features to be evaluated on a wind-averaged basis that takes into account the effects of yaw, and that tractor and trailer manufacturers should be required to certify their drag coefficient results using a common industry standard.[313]

With regard to tire rolling resistance, the committee recommended that since there are numerous variables that contribute to the range of results of test programs, an industry standard (SAE) protocol for measuring and reporting the coefficient of rolling resistance should be developed to aid consumer selection, similar to that proposed for passenger cars.[314]

2. What test procedures and methodologies does NHTSA think is appropriate?

Given the diversity of the MD/HD fleet, as discussed extensively by NAS and summarized above, NHTSA believes that different test procedures and methodologies may be appropriate for different classes of MD/HD vehicles.

Class 2b/3 vehicles:

For Class 2b vehicles and Class 3 pickup trucks, the NAS committee stated that a chassis dynamometer fuel consumption test similar to that used in light-duty vehicles would be a viable option, since these vehicles are often used in ways similar to light-duty vehicles, and existing test facilities could be used.[315] Many of these vehicles are also made in relatively high volume, making a full-vehicle test less difficult to manage for the manufacturer.[316] NAS suggested that this approach would also benefit from being able to rely on existing industry and regulator experience and capability.[317]

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310 Id. at 30, and also Finding 2-4.
311 Id.
312 Id. at 30-31.
313 Id. at 128, Recommendation 5-1.
314 Id., Recommendation 5-2.
315 Id. at 186.
316 Id.
317 Id.

NHTSA agrees that a chassis dynamometer test for Class 2b/3 vehicles is fully practical, since it is already employed by manufacturers and EPA for measuring criteria pollutant emissions from these vehicles, and also by manufacturers and EPA for similar-construction light-duty vehicles. If one of the primary goals of a regulatory program is to minimize additional administrative burden on the regulated industry,[318] then utilizing familiar tests and methodologies, when they exist, will go a long way toward accomplishing that goal.

The NPRM accompanying this Study proposes that 2b/3 vehicle testing be conducted using the same heavy-duty chassis test procedures currently used by EPA for measuring criteria pollutant emissions from these vehicles, but with the addition of the highway fuel economy test cycle (HFET) currently required only for light-duty vehicle GHG emissions and fuel economy testing. Although the highway cycle driving pattern would be identical to that of the light-duty test, other test parameters for running the HFET, such as test vehicle loaded weight, would be identical to those used in running the current EPA Federal Test Procedure for complete heavy-duty vehicles.

The fuel consumption results from vehicle testing on the FTP and the HFET would be weighted by 55 percent and 45 percent, respectively, and then averaged in calculating a combined cycle result. This result corresponds with the data used to develop the proposed load capacity-based fuel consumption standards, since the data on the baseline and technology efficiency was also developed using these test procedures. The addition of the HFET and the 55/45 cycle weightings are similar to the light-duty CAFE program, as we believe the real world driving patterns for Class 2b/3 vehicles are not too unlike those of light-duty trucks, and we are not aware of data specifically on these patterns that would lead to a different choice of cycles and weightings. More importantly, we believe that the 55/45 weightings will provide for effective improvements in fuel consumption from these vehicles, and that other weightings are not likely to improve the program results significantly. This conclusion is based on the fact that the FTP and HFET, weighted at 55/45, provide for a robust exercising of vehicle systems and components that may affect fuel consumption over the range of typical real-world operation for these vehicles, including for the technologies expected to be employed in meeting proposed new standards. The recent light-duty vehicle fuel economy and GHG rulemaking, which will result in the implementation of many of the same technologies, likewise concluded real-world benefits based on the same test procedures and weightings.

Another important parameter in ensuring a robust test program is vehicle test weight. Current EPA testing for 2b/3 vehicle criteria pollutants is conducted with the vehicle loaded to its Adjusted Loaded Vehicle Weight (ALVW), that is, its curb weight plus ½ of the payload capacity. This is substantially more challenging than loading to the light-duty vehicle test condition of curb weight plus 300 pounds, but we believe that this loading for 2b/3 vehicles to ½ payload better fits their usage in the real world and would help ensure that technologies meeting the standards do in fact provide real world

[318] Id. at 179.

reductions. The choice is likewise consistent with use of an attribute based in considerable part on payload for the standard. We see no reason to set test load conditions differently for GHGs and fuel consumption than for criteria pollutants, and we are not aware of any new information (such as real world load patterns) since the ALVW was originally set this way that would support a change in test loading conditions. We are therefore proposing to use ALVW for test vehicle loading in GHG and fuel consumption testing.

We note that the range of vehicles for which NHTSA intends to require chassis dynamometer testing is somewhat greater than that suggested by NAS. For purposes of standards and compliance testing, the NPRM accompanying this Study identifies all vehicles between 8,000 and 14,000 pounds GVWR that are not medium-duty passenger vehicles[319] as Class "2b/3."[320] Thus, beyond the Class 2b vehicles and Class 3 pickup trucks that NAS mentions as appropriate for chassis dynamometer testing, "Class 2b/3" for purposes of the HD National Program proposed by EPA and NHTSA also includes incomplete 2b/3 vehicles sold by OEMs as cab-chassis (chassis-cab, box-delete, bed-delete, cut-away van) vehicles. The agencies propose to use chassis dynamometer testing for these additional vehicles as well as those identified by NAS as "2b/3."

Specifically, for the cab-chassis Class 2b/3 vehicles, because their numbers are relatively small, and to reduce the testing and compliance tracking burden to manufacturers, we would treat these vehicles as equivalent to the complete van or truck product they are derived from. The manufacturer would determine which complete vehicle configuration it produces most closely matches the cab-chassis product leaving its facility, and would include each of these cab-chassis vehicles in the fleet averaging calculations as though it were identical to the corresponding complete vehicle.

We realize that this approach does not capture the likely loss of aerodynamic efficiency involved in converting these vehicles from standard pickup trucks or vans to ambulances and the like, and thus it could assign them lower fuel consumption than they deserve. However, we feel that this approach strikes a fair balance between the alternative options—grouping these vehicles with vocational vehicles subject only to engine standards and tire requirements, or creating a complex and burdensome program that forces OEMs to track, and perhaps control, a plethora of vehicle configurations they currently do not manage.

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[319] A medium-duty passenger vehicle (MDPV) is defined as a motor vehicle over 8,500 pounds GVWR or with a curb weight over 6,000 pounds or with a basic vehicle frontal area over 45 square feet and with a GVWR of less than 10,000 pounds, designed primarily for the transportation of persons, but not an "incomplete truck" (one that does not have the primary load carrying device or container attached), a vehicle that seats more than 12, a vehicle designed for more than 9 persons seated rearward of the driver's seat, or a vehicle that has an open cargo area 72.0 inches or more in interior length (including covered cargo areas, but not ones that are readily accessible from the passenger compartment). *See* 40 CFR 86.1803-01. MDPVs are covered by NHTSA's light truck CAFE standards (*see* 49 CFR Part 533 and 74 Fed. Reg. at 14215 (Mar. 30, 3009]), and are thus subject to EPA's test procedures established pursuant to 49 U.S.C. § 32904(c).
[320] NPRM, Section B(1)(b).

Heavy-duty engines:

As mentioned above, the NAS committee did not expressly recommend particular test methods for HD engines, given that the committee was recommending complete-vehicle standards, but did support the inclusion of engine testing as one part of whole-vehicle testing. When discussing engine testing, the committee stated that using the results from existing engine dynamometer testing for HD vehicles would allow for accurate, repeatable comparisons, but cautioned that there may be a lack of fidelity between the dynamometer test cycle and real-world performance.[321] The committee suggested a number of alternatives to engine dynamometer testing, such as in-use testing, test track testing, chassis dynamometer testing, and simulation modeling, along with a final method requiring the engine dynamometer test cycle to utilize the load characteristics of real trucks over real duty cycles, but simply presented advantages and disadvantages to each without necessarily supporting any of them.[322]

For purposes of HD fuel consumption standard certification and compliance, NHTSA believes that utilizing existing engine dynamometer testing for criteria pollutant emissions will provide the level of accuracy that we need without unduly increasing burden on regulated manufacturers. The NPRM accompanying this study proposes that several engine dynamometer tests be required.

First, the agencies will require low-hour duty cycle engine dynamometer testing using two test methods, the heavy duty transient cycle (characteristic of typical urban stop-and-go driving),[323] and the heavy duty steady-state test (consisting of 13 steady-state modes, in each of which emissions are sampled for a period of five minutes). The agencies believe that is important to assess CO_2 emissions and fuel consumption over both transient and steady-state test cycles, as all vehicles will operate in conditions typical of each cycle at some point in their useful life. However, due to the drive cycle dependence of fuel consumption (and thus CO_2 emissions), which the NAS committee recognized, we do not believe it is reasonable to have a single CO_2/fuel consumption standard that must be met for both cycles. A single CO_2 standard and fuel consumption standard would likely prove to be too lax for steady-state conditions while being too strict for transient conditions. Therefore, we are recommending that all heavy-duty engines be tested over both transient and steady-state tests. However, only the results from either the transient or steady-state test cycles will be used to assess compliance with applicable standards, depending on the type of vehicle the engine will be used in. Engines that will be used in tractor-trailers will use a steady-state test (the ramped-modal cycle or RMC test) for certification, and vocational truck engines will use the FTP transient test. In both cases, results from the other test cycle will be reported but not used for a compliance decision.

[321] March 2010 NAS Report, at 186.
[322] Id.
[323] Besides the Federal Test Procedure (FTP) proposed to be required by the agencies, the agencies are also seeking comment on the use of the World Harmonized Test Cycle (WHTC) for transient testing, which is a somewhat different cycle. Use of the WHTC would provide international harmonization benefits, but the cycle may not be similar enough to the FTP to be an adequate substitute. The agencies are seeking data from manufacturers to answer this question.

And second, the agencies will require engine dynamometer testing for purposes of establishing deterioration factors (DFs) to assess engine durability (that is, that engines comply with emission standards throughout the regulatory compliance period of the engine). The testing required to develop DFs generally involves operating the engine over a representative duty cycle for an extended period of time, typically either half or full useful life, depending on the regulatory class. For engines run to half useful life, emission results are extrapolated out to the full useful life and DFs are then calculated. Throughout testing, manufacturers are required to sample emissions at a low-hour point and final (high-hour) test point. The DFs are then calculated by comparing the high-hour to low-hour test points, either by division or subtraction (for multiplicative and additive DFs, respectively). Additional sample points may be added throughout testing, in which case a linear regression fit is used for calculating emissions at the high-hour point. If emissions are found to have decreased over this test period, DFs of one or zero (for multiplicative and additive DFs, respectively) are assigned, but DFs cannot serve to reduce the final emission values. Given the burden that running an engine out to half or full useful life represents, however, the agencies are considering instead requiring the use of assigned (i.e., not testing-based) DFs for purposes of this first phase of the HD National Program. The agencies have sought comment on this approach.

<u>Combination tractors</u>:

As discussed above, the committee did not recommend chassis dynamometer testing for combination tractors, due to the wide variation in vehicle configurations and consequent burden on manufacturers for testing. Instead, the committee recommended combining engine or powertrain test data with vehicle simulation models, data that could come either from testing, simulation, or a blend of simulation such as hardware-in-the-loop (HIL) or component-in-the-loop (CIL).[324] The committee emphasized that many vehicle duty cycles may need to be simulated or tested in order to achieve adequate fidelity.[325] The committee also stressed that regulators should reinforce rather than impede the fuel consumption sensitivity in Class 8b, and take particular care in defining tests or simulations that can help buyers identify very small (1-2 percent) differences in fuel consumption between vehicles so as to avoid driving incorrect decisions by vehicle manufacturers.[326]

For purposes of HD fuel consumption standard certification and compliance, NHTSA agrees that vehicle simulation is a more reasonable test methodology for line-haul vehicle compliance in the near- to mid-term than attempting to require chassis dynamometer testing. The NPRM accompanying this rule seeks comment on potential future chassis dynamometer testing, but proposes to require vehicle simulation modeling for compliance purposes for this first phase of the HD National Program.

[324] March 2010 NAS report, at 186.
[325] Id.
[326] Id.

The NPRM proposes that vehicle modeling will be conducted using EPA's Greenhouse gas Emissions simulation Model (GEM), which is described in detail in Chapter 4 of the RIA. Basically, this model functions by defining a vehicle model and then exercises this model over various drive cycles. Several initialization files are needed to define a vehicle, which include mechanical attributes, control algorithms, and driver inputs. The majority of these inputs will be predetermined by EPA and NHTSA for the purposes of vehicle certification. The net results from GEM are CO_2 emissions and fuel consumption values over the drive cycle that the user selects. The fuel consumption result will be used for demonstrating compliance with vehicle fuel consumption standards.

The vehicle manufacturer will be responsible for entering aerodynamic properties of the vehicle, the weight reduction, tire properties, idle reduction systems, and vehicle speed limiting systems. For GEM inputs relating to weight reduction, rolling resistance, and aerodynamics, the agencies are proposing the use of lookup tables based on typical performance levels across the industry. These lookup tables do not have data directly related to CO_2, but rather provide the appropriate coefficients for the model to assess CO_2-related (and thus, fuel consumption related) performance. Examples are typical drag coefficients for conventional and SmartWay Class 8 sleeper cabs or coefficients of rolling resistance for standard and low-rolling resistance tires. The exception is for idle reduction technologies, which will have a CO_2 reduction specified in the lookup tables. We believe this approach reduces the testing burden placed upon manufacturers, yet adequately assesses improvements associated with select technologies. The model will be publicly available and will be found on EPA's Web site at http://www.epa.gov/otaq/climate/regulations.htm.

To better facilitate the entry of only the appropriate parameters, EPA will provide a spreadsheet-type template for entering data specific to each vehicle. This template can then be fed directly to the model, which allows the end user to avoid interacting directly with the model and any associated coding. It is expected that this template will be submitted to EPA as part of the certification process for each certified vehicle configuration.

For certification, the model will exercise the vehicle over the same three test cycles as described for the chassis testing option. The model will account for the unique properties of each vehicle and predict the CO_2 emissions on a g/ton-mile basis, as well as fuel consumption (gal/ton-mile) for each test cycle. These results will be weighted in the same manner as described for chassis testing. As with engine and vehicle testing, certification will be based on a parent rating for the test group, representing the worst-case fuel consumption and CO_2 emissions. However, vehicle manufacturers will also have the opportunity to model sub-configurations to determine any benefits that are available on only a select number of vehicles within a test group.

No particular testing requirements are proposed for durability; the agencies anticipate that ensuring that the vehicle remains in its certified configuration throughout the useful life can most effectively be accomplished through engineering analysis, reduced prices of low rolling resistance tires (due to increased market penetration), and specific maintenance instructions provided by the vehicle manufacturer.

Vocational vehicles:

As for combination tractors, the committee did not recommend chassis dynamometer testing for vocational vehicles, due to the wide variation in vehicle configurations and consequent burden on manufacturers for testing. Instead, the committee recommended combining engine or powertrain test data with vehicle simulation models, data that could come either from testing, simulation, or a blend of simulation such as hardware-in-the-loop (HIL) or component-in-the-loop (CIL).[327] Again, the committee emphasized that many vehicle duty cycles may need to be simulated or tested in order to achieve adequate fidelity.[328]

For purposes of HD fuel consumption standard certification and compliance, NHTSA agrees that vehicle simulation is a more reasonable test methodology for vocational truck vehicle standard compliance in the near- to mid-term than attempting to require chassis dynamometer testing. The NPRM accompanying this rule proposes to require vehicle simulation modeling for compliance purposes for this first phase of the HD National Program. Engines intended for use in vocational vehicles would, of course, be subject to the engine test procedures mentioned above.

Vocational truck vehicle testing would be based on dividing vehicles into test groups that are expected to share common emission characteristics and fuel consumption characteristics. Vocational truck regulatory classes share the same structure as those used for heavy-duty engine criteria pollutant certification and are based on gross vehicle weight ratings (GVWR) – this includes light-heavy-duty (LHD) with a GVWR less than 19,500 lbs, medium-heavy-duty (MHD) with a GVWR greater than or equal to 19,500 lbs and less than 33,000 lbs, and heavy-heavy-duty (HHD) with a GVWR greater than or equal to 33,000 lbs. Other test group features may include the type of tires used, intended application, and number of wheels.

Each test group will need to demonstrate compliance with emission and fuel consumption standards using the GEM approach. Additional provisions are available for certification of hybrid vehicles or vehicles using unique technologies, which is further discussed in the Draft Regulatory Impact Analysis. If the test group consists of multiple models, only result from the worst-case model is necessary for certification. However, manufacturers will need to submit to EPA an engineering evaluation demonstrating that the test group has been assembled appropriately and that the test model indeed reflects the worst-case model. Also, manufacturers should plan on submitting tire rolling resistance properties to EPA and NHTSA at the time of certification. Finally the data from each of the certification cycles described below will need to be submitted at the time of certification.

[327] Id.
[328] Id.

For this stage of the HD National Program, the agencies propose that demonstrating compliance with GHG and fuel consumption standards would primarily involve demonstrating the use of low rolling resistance tires and quantifying the associated CO_2 and fuel consumption performance. Similar to combination tractors, this will be done using GEM. However, the input parameters entered by the vehicle manufacturer will be limited to the properties of the tires. GEM will use the tire data, along with a baseline truck and engine, to generate a complete vehicle model. The test weight used in the model will be based on the vehicle class, as identified above. Light-heavy duty vehicles will have a test weight of 16,000 lbs, 25,150 lbs for medium-heavy duty vehicles, and heavy-heavy duty vocational vehicles will use a test weight of 67,000 lbs. The model will then be exercised over the HHDDT transient cycle as well as 55 and 65 mph steady-state cruise conditions. The results of each of the three tests will be weighted at 37 percent, 21 percent, and 42 percent for 65 mph, 55 mph, and transient tests, respectively.

The agencies recognize that it may seem more expedient and just as accurate to require manufacturers use tires meeting certain industry standards for qualifying tires as having low rolling resistance. In addition, CO_2 and fuel consumption benefits could be quantified for different ranges of coefficients of rolling resistance to provide a means for comparison to the standard. However, we believe that as technology advances, other aspects of vocational vehicles may warrant inclusion in future rulemakings. For this reason, we believe it is important to have the certification and compliance framework in place to accommodate such additions. While the modeling approach may seem to be overly complicated for this phase of the rule, it also serves to create a certification and compliance pathway for future rulemakings and therefore we believe this is the best approach.

No particular testing requirements are proposed for durability; the agencies are seeking comment on how to account for useful life compliance for vocational vehicles.

<u>Component testing</u>:

As mentioned above, the committee provided recommendations with regard to test procedures for two components that can significantly impact fuel consumption (and thus CO_2 emissions) for certain HD vehicles, aerodynamic drag reducing technologies and low rolling resistance tires. With regard to aerodynamic drag, the committee stated that wind tunnel testing is the only accurate method to measure aerodynamic drag force directly, because it can directly account for yaw (sideways) forces.[329] When possibly combined with CFD codes, which perform millions of computer calculations to simulate the interaction of fluids and gases with the complex exterior surfaces of the vehicle, the committee suggested that a wind tunnel approach was preferable over coast-down testing for measuring aerodynamic drag.[330] Thus, the committee recommended that regulators require aerodynamic features to be evaluated on a wind-averaged basis that takes into account the effects of yaw, and that tractor and trailer manufacturers should be required

[329] Id. at 30, and also Finding 2-4.
[330] Id.

to certify their drag coefficient results using a common industry standard.[331] However, the committee recommended further examination of the validity, accuracy, and precision of different methods for measuring aerodynamic drag.

With regard to tire rolling resistance, the committee recommended that since there are numerous variables that contribute to the range of results of test programs, an industry standard (SAE) protocol for measuring and reporting the coefficient of rolling resistance should be developed to aid consumer selection, similar to that proposed for passenger cars.[332]

For purposes of evaluating aerodynamic drag to determine inputs for compliance testing for HD fuel consumption standards, NHTSA agrees that wind tunnel testing can be beneficial, but believes that there are counter-balancing concerns that make its exclusive use impractical for the first phase of the proposed HD National Program. For purposes of the NPRM accompanying this study, the agencies are proposing to allow coast-down testing, wind tunnel testing, and CFD to be used to generate aerodynamic drag inputs for use in compliance simulation modeling. Input values would then assigned to pre-defined bins, and the defined bin value would be used for the actual modeling. The agencies are allowing all three methods for determining input values because all have pros and cons, and because all are currently used by the industry. We note that aerodynamic drag input values are only relevant for combination tractors; compliance simulation modeling for vocational vehicles does not require aerodynamic drag values as inputs, and Class 2b/3 trucks are tested on a chassis dynamometer.

Coast down testing pros and cons:

The coast down test procedure has been used extensively in the light-duty industry to capture the road load force by coasting a vehicle along a flat straightaway under a set of prescribed conditions. Coast down testing has been used less extensively to obtain road load forces for medium- and heavy-duty vehicles. EPA has conducted a significant amount of test work to demonstrate that coast down testing per SAE J2263 produces reasonably repeatable test results for Class 7 and 8 tractor/trailer pairings, as described in Chapter 3 of the DRIA. The agencies propose that a manufacturer that chooses this method would determine a tractor's Cd value through analysis of the road load force equation derived from SAE J2263 Revised 2008-12 test results.

Wind tunnel testing pros and cons:

A wind tunnel provides a stable environment yielding a more repeatable test than coast down. This allows the manufacturer to run multiple baseline vehicle tests and explore configuration modifications for nearly the same effort (e.g., time and cost) as conducting the coast down procedure. In addition, wind tunnels provide testers with the ability to yaw the vehicle at positive and negative angles relative to the original centerline

331 Id. at 128, Recommendation 5-1.
332 Id., Recommendation 5-2.

of the vehicle to accurately capture the influence of non-uniform wind direction on the Cd (e.g., wind averaged Cd).

However, there are challenges with the use of wind tunnels in a regulatory program that would need to be addressed in order for manufacturers to use this method. There are several different configurations and types of wind tunnels. There are wind tunnels that use forced air (fan upstream pushing air through the wind tunnel) versus suction (fan downstream and pulling air through the wind tunnel). There are wind tunnels with open or semi-open jet, closed jet, and slotted or adaptive wall test sections. There are wind tunnels with static floors versus moving floors or suction that compensate for the boundary layer of air that builds up at the ground level. Finally, there are full-scale wind tunnels (e.g., dimensions as large as 80 feet times 120 feet in the test section) that can accommodate a full-size vehicle or clay model versus reduced-scale wind tunnels (e.g., dimensions as small as 3 feet by 4.5 feet) that require the vehicle to be scaled down in model form. In addition, regardless of wind tunnel type there are several factors that would need to be minimized or addressed by applying correction factors to maintain flow quality including but not limited to ground boundary layer thickness and location; flow uniformity, angularity and fluctuation; turbulence and wall interference, and environmental conditions (e.g., temperature, humidity, air/fluid density) in the tunnel.

As a result of the wind tunnel testing issues and configuration complexities, it would be difficult to develop a new, uniform wind tunnel testing standard for this rulemaking. Therefore, the agencies propose to use the established SAE standards (such as SAE J1252 Revised 1981-07) and recommended practices, with some modifications and exceptions, for wind tunnel aerodynamic assessment.

<u>Computational Fluid Dynamics pros and cons</u>:

Computational Fluid Dynamics, or CFD, capitalizes on today's computing power by modeling a full size vehicle and simulating the flows around this model to examine the fluid dynamic properties, in a virtual environment. CFD tools are used to solve the Navier-Stokes equations that follow physical law of conservation of momentum and govern fluid dynamics and flow relationship around a body in motion or a static body with fluid in motion around it. CFD analysis involves several steps: defining the model structure or geometry based on provided specifications to define the basic model shape, applying a closed surface around the structure to define the external model shape (wrapping or surface meshing), dividing the control volume, including the model and the surrounding environment, up into smaller, discreet shapes (gridding), defining the flow conditions in and out of the control volume and the flow relationships within the grid (including eddies and turbulence), and solving the flow equations based on the prescribed flow conditions and relationships.

This approach can be beneficial to manufacturers since they can rapidly prototype (e.g., design, research, and model) an entire vehicle without investing in material costs; they can modify and investigate changes easily; and the data files can be re-used and shared within the company or with corporate partners.

As with the two aerodynamic assessment methods mentioned above, CFD has challenges that must be addressed. Although it can save on material cost, it can be time consuming (manpower cost) and requires significant computing power depending on the model detail (information technology costs). As described above, a considerable amount of time goes into defining the shape, meshing or gridding the shape and the environment, and solving all of the associated flow equations. Meshes/grids in CFD can contain anywhere from 1 million to 100 million individual cells depending on the modeler's criteria. Consequently, run times needed to solve all of the flow relationships can be extremely long.

The accuracy of the outputs from CFD analysis is highly dependent on the inputs. The CFD modeler decides what method to use for wrapping, how fine the mesh cell and grid size should be, and the physical and flow relationships within the environment. A balance must be achieved between the number of cells, which defines how fine the mesh is, and the computational times for a result (i.e., solution-time-efficiency). All of these decisions affect the results of the CFD aerodynamic assessment.

In addition, CFD software tools have difficulty solving for complex turbulent flows and the spatial interaction that occurs in real-world aerodynamics. This source can lead to large errors between the actual and predicted aerodynamic characteristics. Therefore, care must be taken to ensure that the various turbulent flows and ground/wall interference affects are accounted for.

As with any software tool, the CFD software marketplace is vast and ever-evolving at an astonishing pace. There are commercially-available CFD software tools and publicly-available customized CFD software tools used by academia and government agencies. Any attempt to require one particular CFD software tool in a rulemaking would nearly guarantee its obsolescence by the time the rule was published. In addition, no two CFD software tools are alike and there are currently no established SAE standards or recommended practices, that we are aware of, governing the use of CFD. As a result, it is difficult propose a particular CFD software tool or approach in a regulatory arena. Much of recent research has examined the correlation of CFD to experimental results and to determine the sensitivity of the results to certain aspects of CFD (e.g., varying cell size and shape, grid size and meshing technique). This research can aid in defining boundaries for the use of CFD in aerodynamic assessment. Thus, CFD does have some ability to accurately model aerodynamic assessments, if conditions for performing the analysis are appropriately defined.

We note that the NAS committee encouraged the Society of Automotive Engineers Truck and Bus Aerodynamic and Fuel Economy Committee, "to bring the various current SAE procedures and practices into the needs of the 21st century."[333] Part of undertaking this update would be to determine the adequacy of influencing parameter control pertinent to each aerodynamic validation process, including CFD. The committee suggested that variables of concern include vehicle speed, wind speed and direction

[333] Id. at 30.

(yaw), temperature, humidity, wind tunnel variables, geometry modeling, flow modeling, fuel, lubricants, and driver to achieve a set of precision and accuracy tolerances to help understand the variability with various aerodynamic validation methods.

To address these considerations, the agencies propose a minimum set of criteria applicable to using CFD for aerodynamic assessment. Further, we are proposing a requirement to correlate CFD aerodynamic assessments with experimental results from either or both the coast down procedure and wind tunnel testing, within a certain tolerance level. This will allow the use of CFD and the design freedom that it offers while ensuring that, regardless of the decisions made during the process, the CFD aerodynamic assessment accurately simulates real-world aerodynamics.

Given the pros and cons of these different measurement methodologies, the agencies are proposing that the coefficient of drag assessment be a product of test data and modeling using good engineering judgment, keyed to determining the Cd value that would result from coast down testing per SAE J2263 of the vehicle. This is a similar approach that EPA has provided as an option in testing light duty vehicles where the manufacturers supply representative road load forces for the vehicle.[334]

The agencies are also interested in developing an acceptance demonstration process for aerodynamic testing in the final rulemaking. As part of the process, the manufacturer would have to demonstrate to EPA and NHTSA that the methodology used for aerodynamic assessment is acceptable prior to using it for aerodynamic assessment. In addition to the acceptance demonstration, alternative methods would also require correlation testing to the coast down procedure using a reference vehicle. This process would provide confidence in the use of the alternative method once this rule is implemented. The NPRM seeks comment on the proposed requirements for each allowed method, standards and practices that should be used and any unique criteria that we are proposing.

In addition, EPA and NHTSA recognize that wind conditions have a greater impact on real world CO_2 emissions and fuel consumption of heavy duty trucks than of light duty vehicles. As the NAS committee stated, the wind average drag coefficient is about 15 percent higher than the zero degree coefficient of drag (Cd).[335] The large ratio of the side area of a combination tractor and trailer to the frontal area illustrates that winds will have a significant impact on the drag. One disadvantage of the agencies' proposed approach to aerodynamic assessment is that the test methods have varying degrees of ability to assess wind conditions. Wind tunnels are currently the only demonstrated tool to accurately assess the influence of wind speed and direction on a truck's aerodynamic performance. Both the coast down tests and computational fluid dynamics modeling have limited ability in assessing yaw conditions. To address this issue, the agencies are proposing to use coefficient of drag values that represent zero yaw (i.e., representing wind from directly in front of the vehicle, not from the side). The agencies recognize that the results of using the zero yaw approach will produce fuel

[334] For more information, see 49 CFR Part 86.129-00 (e)(1).
[335] March 2010 NAS Report at 39, Finding 2-4.

consumption results in the regulatory program that are slightly lower than in-use but we believe this approach is appropriate since not all manufacturers will use wind tunnels for the aerodynamic assessment. In addition, this approach should not affect technology effectiveness or change the kinds of technology decisions made by the tractor manufacturer. However, the agencies are interested in receiving comment on approaches to develop wind averaged coefficient of drag values using CFD, coast down, and constant speed test procedures.

NHTSA and EPA are proposing that manufacturers take the aerodynamic test result from a truck and determine the appropriate bin (e.g., Classic, Conventional, SmartWay, etc.), as defined in Section II of the NPRM accompanying this study. The agencies are proposing the aerodynamic bin approach to address the variability in the proposed testing methods. Further information about the specifics of the bin system are available in the NPRM, and we refer the reader there for that information.

For purposes of evaluating tire rolling resistance to determine inputs for compliance testing for HD fuel consumption standards, NHTSA agrees with the committee that a standardized methodology for measuring and reporting the coefficient of rolling resistance should be developed to aid consumer selection, similar to that proposed for passenger cars. Therefore, in the NPRM accompanying this study, the agencies are proposing that the tractor's tire rolling resistance input to GEM be determined using the ISO 28580:2009 test method.[336] The ISO test procedure is the same one used by NHTSA in its tire fuel efficiency labeling program for light-duty vehicles[337] and is consistent with the direction being taken by the tire industry both in the United States and Europe. The rolling resistance from this test would be used to specify the rolling resistance of each tire on the steer and drive axle of the vehicle. The results would be expressed as a rolling resistance coefficient and measured as kilogram per ton (kg/ton). The agencies are proposing that three tire samples within each tire model be tested to account for some of the production variability and the average of the three tests would be the rolling resistance coefficient for the tire. GEM would use a combined tire rolling resistance where 15 percent of the gross weight of the truck and trailer would be distributed to the steer axle, 42.5 percent to the drive axles, and 42.5 percent to the trailer axles.[338] The trailer tires' rolling resistance would be prescribed by the agencies as part of the standardized trailer used for demonstrating compliance at 6 kg/ton, which was the average trailer tire rolling resistance measured during the SmartWay tire testing.[339]

[336] ISO, 2009, Passenger Car, Truck, and Bus Tyres – Methods of Measuring Rolling Resistance – Single Point Test and Correlation of Measurement Results: ISO 28580:2009(E), First Edition, 2009-07-01.
[337] NHTSA, 2009. "NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 1 – Evaluation of Laboratory Test Protocols." DOT HS 811 119. June. (www.regulations.gov, Docket ID: NHTSA-2008-0121-0019).
[338] This distribution is equivalent to the Federal over-axle weight limits for an 80,000 GVWR 5-axle tractor-trailer: 12,000 pounds over the steer axle, 34,000 pounds over the tandem drive axles (17,000 pounds per axle) and 34,000 pounds over the tandem trailer axles (17,000 pounds per axle).
[339] EPA, SmartWay Transport Partnership July 2010 e-update, Available at http://www.epa.gov/smartwaylogistics/newsroom/documents/e-update-july-10.pdf (last accessed July 16, 2010).

We recognize, however, that the useful life of original equipment tires used on tractors is shorter than the tractor's useful life. For purposes of the proposed HD National Program, the agencies are treating the tires as if the owner replaces the tire with tires that match the original equipment. Some owners opt for the original tires under the assumption that this is the best product, but we recognize that tractor tires are often retreaded or replaced before 100,000 miles. The agencies are seeking comments in this area, and are specifically seeking data for the rolling resistance of retread and replacement heavy duty tires and the typical useful life of tractor tires.

The agencies are mindful of NAS' concerns with respect to accuracy, repeatability, and fairness of test procedures given the considerable diversity of the HD vehicle fleet, and have done our best in the NPRM accompanying this study to address them in the most practical way possible for the program we are looking to implement. NHTSA and EPA will continue to research and evaluate appropriate test procedures and methodologies during the rulemaking for this first phase of the HD National Program, and will likely continue to do so even after the initial rulemaking simply as a matter of good regulatory practice. We anticipate that comments received in response to the proposal will help to guide our thinking further for the final rule.

C. What metric(s) would be appropriate for measuring and expressing MHDV fuel efficiency performance?

1. What did NAS recommend?

As discussed above, the committee recommended that NHTSA choose a performance-based metric that (1) incentivized subcomponent and total vehicle development; (2) related to the transport task or vehicle vocation; (3) encouraged energy conservation for a given task; and (4) was based on energy/fuel consumption (normalized to equivalent diesel fuel). To address these principles, the committee recommended that the metric chosen include a factor for the work performed – e.g., gallons/cargo ton-mile instead of simply gallons/mile – but also consider the task performed in the case of vehicles that transport light-density freight that "cubes out" rather than "weighs out."

Thus, for purposes of combination tractors, the committee generally recommended a metric of gallons/ton-mile (with the caution for light-density freight). For purposes of vocational vehicles, the committee concluded that given the variability of these vehicles and the many factors that influence their fuel consumption, a single metric applied identically to all classes of vehicles could be problematic, but that a standard measurement protocol coupled with different standards and metrics could provide a means of assessing fuel consumption on the basis of work task for these vehicles.[340] For purposes of Class 2b/3 vehicles, the committee suggested that their high production volume could make several general metrics appropriate – either gallons/mile, gallons/mile-person weight, or gallons/ton-mile. The committee also suggested that

[340] March 2010 NAS Report at 184.

metrics for standards applicable to buses would need to account for passenger mass and freight (cargo) mass per miles traveled.[341]

2. What metrics does NHTSA think are appropriate, taking into consideration, among other things, the work performed by such vehicles and types of operations in which they are used?

NHTSA agrees that measurement metrics for HD vehicles must account for the work that they perform and the types of operations in which they are used. Thus, in the NPRM accompanying this study, the agencies are proposing test metrics that express fuel consumption and GHG emissions relative to the most important measures of heavy-duty truck utility for that segment. Specifically, for heavy-duty pickup trucks and vans, EPA and NHTSA are proposing standards on a per-mile basis (g/mile for the EPA standards, gallons/100 miles for the NHTSA standards). For heavy-duty trucks, both line-haul combination and vocational, the agencies are proposing standards expressed in terms of the key measure of freight movement tons of payload miles or, more simply, ton-miles. Hence, for EPA the proposed standards are in the form of the mass of emissions from carrying a ton of cargo over a distance of one mile (g/ton-mi), and the proposed NHTSA standards are in terms of fuel consumed over a set distance (one thousand miles), or gal/1,000 ton-mile. Additionally, since the agencies are also setting standards for engines, the engine metric is based on gallons used or emissions produced per unit of work – thus, NHTSA's engine standards are based on gallons/brake-horsepower-hour (gal/100 bhp-hr) and EPA's engine standards are based on grams of CO_2/brake-horsepower-hour (g/bhp-hr). We explain below how these different metrics reflect and account for the work performed by these different classes of vehicles.

<u>HD pickup trucks and vans</u>:

The large majority of HD pickups and vans are ¾-ton and 1-ton pickup trucks, 12- and 15-passenger vans, and large work vans that are sold by the original equipment manufacturers (OEMs) as complete vehicles, with no secondary manufacturer making substantial modifications prior to registration and use. These OEMs are companies with major light-duty markets in the U.S., primarily Ford, General Motors, and Chrysler. Furthermore, the technologies available to reduce GHG emissions from this segment are similar to the technologies used on light-duty pickup trucks, including both engine efficiency improvements (for gasoline and diesel engines) and vehicle efficiency improvements. As NAS noted, high production volumes for these vehicles (and their similarity to light-duty vehicles) make a metric consistent with light-duty vehicles appropriate.

Therefore, in the NPRM accompanying this study, the agencies are proposing fuel consumption and GHG standards for HD pickups and vans based on the whole vehicle, including the engine, expressed as gal/mile and g/mile, consistent with the way these vehicles are regulated by EPA today for criteria pollutants and also similar to how the

[341] Id.

light-duty counterparts of these vehicles are regulated by NHTSA[342] and EPA. Additionally, the agencies recognize that weight-based measures such as payload and towing capability are key among the things that characterize differences in the design of HD pickups and vans, as well as differences in how these vehicles will be utilized. Buyers consider these utility-based attributes when purchasing a heavy-duty pickup or van. Payload has a particularly important impact on the test results for HD pickup and van emissions and fuel consumption, because testing under existing EPA procedures for criteria pollutants is conducted with the vehicle loaded to half of its payload capacity (rather than to a flat 300 lb as in the light-duty program), and the correlation between test weight and fuel use is strong. While towing does not directly factor into test weight as nothing is towed during the test, towing capacity can be a significant factor to consider because HD pickup truck towing capacities can be quite large, with a correspondingly large effect on design. The proposed HD National Program therefore sets gal/mile and g/mi standards for HD pickups and vans based on a work/load capacity factor that combines their payload[343] and towing capabilities, in pounds, with an added fixed adjustment for 4-wheel drive vehicles, thus accounting for the work performed by these vehicles. Under our proposal, target GHG and fuel consumption standards would be determined for each vehicle with a unique work factor. These targets would then be production weighted and summed to derive a manufacturer's annual fleet average standards.

The agencies recognize that the payload/towing-dependent gram per mile and gallon per mile standards for HD pickups and vans parallel the gram per ton-mile and gallon per ton-mile standards being proposed for Class 7/8 line-haul combination tractors and vocational vehicles. Both approaches account for the fact that more work is done, more fuel is burned, and more CO_2 is emitted in moving heavier loads than in moving lighter loads. Both of these load-based approaches avoid penalizing truck designers wishing to reduce GHG emissions and fuel consumption by reducing the weight of their trucks. However, we believe that the sizeable diversity in HD pickup and van applications, which go well beyond simply transporting freight, and the fact that the curb weights of these vehicles are on the order of their payload capacities, caution against setting a simple g/ton-mile or gal/ton-mile standard for them. The payload/towing-dependent standards proposed account for the work performed by these vehicles, and are thus consistent with NAS' recommendations.

[342] NHTSA uses a mile per gallon (mpg) metric for light-duty pickups and vans regulated under 49 CFR Part 533, as required by EPCA, which defines "fuel economy" for purposes of CAFE standards in terms of miles per gallon. See 49 U.S.C. § 32901(a)(11). For purposes of the HD standards, which are set under 49 U.S.C. § 32902(k), NHTSA interprets the mandate to develop a "fuel efficiency improvement program" as not requiring the use of a mile per gallon metric.

[343] To ensure consistency and help preclude gaming, we are proposing that payload capacity be defined as GVWR minus curb weight, and towing capacity as GCWR minus GVWR. We are proposing that, for purposes of determining the work factor, GCWR be defined according to SAE Recommended Practice J2807 APR2008, GVWR be defined consistent with EPA's criteria pollutants program, and curb weight be defined as in 40 CFR § 86.1803-01.

Vocational vehicles:

Class 2b-8 vocational vehicles consist of a wide variety of truck types. Some of the primary applications for trucks in this segment include delivery, refuse, utility, dump, and cement trucks; transit, shuttle, and school buses; emergency vehicles, motor homes, tow trucks, and many more. These trucks and their engines contribute approximately 15 percent of today's heavy-duty truck sector GHG emissions.

As discussed above, EPA and NHTSA have concluded that reductions in GHG emissions and fuel consumption require addressing both the vehicle and the engine. As discussed above for Class 7 and 8 combination tractors, the agencies are each proposing two sets of standards for Class 2b-8 vocational vehicles. For vehicle-related emissions, the agencies are proposing standards for chassis manufacturers that would be expressed in terms of moving a ton of payload over one mile: EPA CO_2 (g/ton-mile) standards and NHTSA fuel consumption (gal/1,000 ton-mile) standards). The agencies believe that this moving-of-payload metric is appropriate in the case of vocational vehicles because only low rolling resistance tires are evaluated for vehicle-related standard purposes. As is the case for line-haul combination tractors, the manufacturers of the engines intended for vocational vehicles would be subject to separate engine-based standards.

Combination tractors:

HD line-haul combination trucks are built to move freight. The metric for these vehicles should therefore reflect what the regulator wishes to control (CO_2 or fuel consumption) relative to the clearest value of its use; in this case, as NAS identified, carrying freight or passengers, or stated another way, moving its payload from one location to another. It should also encourage efficiency improvements that will lead to reductions in emissions and fuel consumption during real-world operation. The NAS committee therefore concluded that the most appropriate way to represent an attribute-based fuel consumption metric for combination tractors is to normalize the fuel consumption to the payload.

The ability of a truck to meet a customer's freight transportation requirements depends on three major characteristics of the tractor: the GVWR (which establishes the maximum carrying capacity of the tractor and trailer), the cab type (sleeper cabs provide overnight accommodations for drivers), and the tractor roof height (to mate tractors to trailers for the most efficient configuration). Each of these attributes impacts the baseline fuel consumption and GHG emissions, as well as the effectiveness of possible technologies, like aerodynamics, and is discussed in more detail below.

The first tractor characteristic to consider in determining an appropriate metric is payload, which is determined by a tractor's GVWR and GCWR relative to the weight of the tractor, trailer, fuel, driver, and equipment. Class 7 trucks, which have a GVWR of 26,000-33,000 pounds and a typical GCWR of 65,000 pounds, have a lesser payload capacity than Class 8 trucks. Class 8 trucks have a GVWR of greater than 33,000 pounds and a typical 80,000 pound GCWR. In the NPRM accompanying this study, the agencies are proposing, consistent with NAS' recommendation, a load specific fuel consumption metric (g/ton-mile and gal/ton-mile) where the "ton" represents the amount of payload. The amount of payload that a Class 7 truck can carry is less than the Class 8 truck's payload capacity. Generally, higher payload capacity trucks have better specific fuel consumption and GHG emissions than lower payload capacity trucks. Therefore, the baseline fuel consumption and GHG emissions performance per ton-mile differs between the categories. It is consequently reasonable to distinguish between these two vehicle categories, so that the agencies are proposing separate standards for Class 7 and Class 8 tractors.[344]

A default payload is specified for each of the tractor categories. We propose to adjust the payload based on vehicle mass reductions because we estimate that approximately one third of the time the amount of freight loaded in a trailer is limited not by volume in the trailer but by the total gross vehicle weight rating of the tractor. By reducing the mass of the tractor the mass of the freight loaded in the tractor can go up. Based on this general approach, it can be estimated that for every 1,200 pounds in mass reduction, total truck vehicle miles traveled and therefore trucks on the road could be reduced by one percent. Without the use of a per ton-mile metric it would not be clear or straightforward for the agencies to reflect the benefits of mass reduction from large freight carrying vehicles that are often limited in the freight they carry by the GVWR of the truck. However, the agencies are seeking comment to address NAS' concern about "cubed-out vehicles," specifically, whether other metrics such as per cube-mile should be considered instead.

The second characteristic that affects fuel consumption and GHG emissions, and thus the consideration of a metric, is the relationship between the tractor cab roof height and the type of trailer used to carry the freight. The primary trailer types are box, flat bed, tanker, bulk carrier, chassis, and low boys. Tractor manufacturers sell tractors in three roof heights – low, mid, and high. The manufacturers do this to obtain the best aerodynamic performance of a tractor-trailer combination, resulting in reductions of GHG emissions and fuel consumption, because it allows the frontal area of the tractor to be similar in size to the frontal area of the trailer. In other words, high roof tractors are designed to be paired with a box trailer while a low roof tractor is designed to pull a flat bed trailer. The baseline performance of a high roof, mid roof, and low roof tractor

[344] The agencies considered, but are not proposing to set, a single standard for both Class 7 and 8 tractors based on the payload carrying capabilities and assumed typical payload levels of Class 8 tractors alone. Such a single standard would penalize Class 7 vehicles in favor of Class 8 vehicles, and, we believe, could have the perverse impact of increasing fuel consumption and GHG emissions. The greater capabilities of Class 8 tractors, and their related greater efficiency when measured on a per ton-mile basis, are only relevant in the context of operations where that greater capacity is needed. For many applications such as regional distribution, the trailer payloads dictated by the goods being carried are lower than the average Class 8 tractor payload. In those situations, Class 7 tractors are more efficient than Class 8 tractors when measured on a per ton-mile of actual freight carried. This is because the extra capabilities of Class 8 tractors add additional weight to vehicle that is only beneficial in the context of its higher capabilities. The existing market already selects for vehicle performance based on the projected payloads. By setting separate standards, the agencies seek to avoid providing an advantage or disadvantage to Class 7 or 8 tractors relative to one another, and to continue to allow trucking fleets to purchase the vehicle most appropriate to their business practices.

differs due to the variation in frontal area, which determines the aerodynamic drag. For example, the frontal area of a low roof tractor is approximately 6 square meters while a high roof tractor has a frontal area of approximately 9.8 square meters. Therefore, as explained below, the agencies are proposing that the roof height of the tractor determine the trailer type required to be used to demonstrate compliance of a truck with the fuel consumption and CO_2 emissions standards. As with vehicle weight classes, setting separate standards for each tractor roof height helps ensure that all tractors are regulated to achieve appropriate improvements, without inadvertently leading to increased emissions and fuel consumption by shifting the mix of vehicle roof heights offered in the market away from a level customarily tied to the actual trailers vehicles will haul in-use.

Tractor cabs typically can be divided into two configurations – day cabs and sleeper cabs. Line haul operations typically require overnight accommodations due to Federal Motor Carrier Safety Administration hours of operation requirements. Therefore, some truck buyers purchase tractor cabs with sleeping accommodations, also known as sleeper cabs, because they do not return to their home base nightly. Sleeper cabs tend to have a greater empty curb weight than day cabs due to the larger cab volume and accommodations that lead to a higher baseline fuel consumption for sleeper cabs when compared to day cabs. In addition, there are specific technologies, such as extended idle reduction technologies, which are appropriate only for tractors that hotel -- such as sleeper cabs. To respect these differences, the agencies are proposing to create separate standards for sleeper cabs and day cabs.

To account for the relevant combinations of these attributes, the agencies therefore propose to segment combination tractors into the following nine regulatory subcategories:

- Class 7 Day Cab With Low Roof
- Class 7 Day Cab With Mid Roof
- Class 7 Day Cab With High Roof
- Class 8 Day Cab With Low Roof
- Class 8 Day Cab With Mid Roof
- Class 8 Day Cab With High Roof
- Class 8 Sleeper Cab With Low Roof
- Class 8 Sleeper Cab With Mid Roof
- Class 8 Sleeper Cab With High Roof

The agencies have not identified any Class 7 or Class 8 day cabs with mid roof heights in the market today but welcome comments to the proposed HD National Program with regard to this market characterization.

Thus, for the reasons described above, in the NPRM accompanying this study, the agencies are proposing standards for Class 7 and 8 combination tractors that would be expressed in terms of moving a ton (2,000 pounds) of freight over one mile. Thus, NHTSA's proposed fuel consumption standards for these trucks would be represented as gallons of fuel used to move one ton of freight 1,000 miles, or gal/1,000 ton-mile. EPA's proposed CO_2 vehicle standards would be represented as grams of CO_2 per ton-mile. This is consistent with NAS' recommendation.

Engine standards:

NAS did not provide express recommendations for engine standard metrics because the committee focused on complete-vehicle standards rather than separate engine and vehicle standards. For purposes of the NPRM accompanying this study, however, the agencies were guided by NAS' principles for metrics nonetheless in determining a proposed metric for HD engine standards. Specifically, the agencies are setting engine standards in terms of brake-horsepower-hours, or bhp-hr – gal/100 bhp-hr for fuel consumption, and g/bhp-hr for CO_2 emissions. Bhp is the measure of an engine's horsepower – its work – without the loss in power caused by the gearbox, alternator, differential, water pump, and other auxiliary components such as power steering pump, muffled exhaust system, etc. *Brake* refers to a device that was used to load an engine and hold it at a desired RPM. The agencies believe that basing the engine standard metric on bhp is consistent with the work that engines perform, and should encourage energy conservation, as recommended by NAS with respect to the metrics for vehicle standards. Additionally, bhp-based fuel consumption and GHG standards would be consistent with EPA's existing non-GHG emissions regulations for heavy duty on highway engines, providing the further benefit of reducing testing and calculation burden on manufacturers in assessing compliance.

D. What is the range of factors that affect MD/HD fuel efficiency?

As discussed above, Congress directed NHTSA to consider

> …the range of factors, including, without limitation, design, functionality, use duty cycle, infrastructure, and total overall energy consumption and operating costs that affect commercial medium- and heavy-duty on-highway vehicle and work truck efficiency.

49 U.S.C. § 32902(k)(1)(C). While the general intent is clear – Congress wanted NHTSA to be mindful of the listed factors in developing standards to implement a fuel efficiency improvement program for MD/HD vehicles – some of the particular factors that Congress identified are somewhat ambiguous given their context. "Design," "functionality," and "use" all appear to refer to how the different tasks performed by MD/HD vehicles influence their physical characteristics and thus affect the fuel efficiency-improving technologies that can reasonably be applied to them. "Duty cycle" likely refers to the fact that because the design, functionality, and use of MD/HD vehicles vary so greatly, NHTSA should consider and be mindful of these factors in selecting appropriate duty cycles for compliance testing, and also consider the extent to which the fuel efficiency of a vehicle may vary depending on the duty cycle.

"Infrastructure," in this context, is more ambiguous. It could refer to the effect of road infrastructure on MHDV fuel efficiency, as when crowded highways keep combination tractors from maintaining steady-state performance and thus force them to operate at lower speeds and consume more fuel, or when MD/HD vehicles are equipped with ITS technologies to improve their efficiency by informing them about best routes, etc., or when vehicle size and weight limits prevent MD/HD vehicles from taking the most direct route to their location. It could refer to vehicle electrification infrastructure, as when insufficient charging stations for plug-in hybrid applications prevent MD/HD vehicles from running more frequently on grid-derived electricity, or when truck stops do not have electrified parking spaces to allow tractors to idle using grid electricity rather than their engines. Or, it could refer somehow to infrastructure to encourage intermodal shifts, as when insufficient rail capacity forces more freight to trucks, requiring more trucks on the roads. For purposes of this study, NHTSA has done its best to consider the infrastructure-related issues identified by the NAS committee, although solving many of them is beyond the scope of NHTSA's statutory authority.

"Total overall energy consumption and operating costs" is also ambiguous in this context – it is not immediately clear how these could affect MHDV fuel efficiency. Upon careful consideration, NHTSA interprets these factors as likely referring to the "rebound effect," which refers to the fact that as fuel efficiency improves (due to regulation, for example), the cost of driving/transporting goods by truck decreases, which leads to increases in truck traffic in response, which offsets some of the reductions in overall energy consumption that occurred in the first place due to the improved fuel efficiency of the vehicles.

This study will consider these factors, as defined above, in turn.

1. What factors did NAS consider?

Design, functionality, and use:

The NAS committee devoted all of Chapter 2 and a number of other sections of the report to detailing the impact of the diversity of designs and uses of vehicles in the MHDV fleet on the fuel efficiency of those vehicles. As discussed above, Chapter 2 describes the wide variety of truck and bus types and applications, noting that their variety of designs and uses results in a broad range of duty cycles, from high-speed operation with few stops on highways to lower speed urban operation with dozens of stops per mile.[345] Some trucks haul cargo (and some buses haul passengers and cargo) over long distances, some trucks haul materials or waste (and some buses haul passengers) over short distances, some trucks carry equipment (like bucket trucks) for varying distances and then do work once they reach their destination. The NAS committee recognized that in characterizing the fuel efficiency of a whole vehicle (or of a chassis or mule created to mimic a whole vehicle) against a standard, it is essential to exercise the vehicle through a prescribed speed-time sequence that reasonably reflects actual use.[346]

[345] March 2010 NAS report, at 17.
[346] Id. at 31.

Duty cycles:

The NAS committee stated that in order to determine a reasonable prescribed speed-time sequence to reflect actual use, engineers typically assemble duty cycles by combining real-world truck activity data.[347] An activity database may be created by logging speed from one or many trucks over a representative period of time, and then the log may be divided into "trips" or "microtrips" (with idle activity either separate or included), which are then connected to form a cycle of desired length.[348] The cycle that is statistically most representative of the whole database, using metrics such as average speed and standard deviation of speed, is chosen as a representative cycle.[349] The committee identified EPA's Heavy-Duty Urban Dynamometer Driving Schedule (UDDS) as an example of a vehicle conditioning cycle representing "freeway" and "non freeway" activity,[350] and the suite of "modes" of the Heavy Heavy-Duty Diesel Truck (HHDDT) schedule used in the E-55/59 California truck emissions inventory program as an example representing idle, creep, transient, cruise, and high-speed cruise modes reflecting progressively higher average speeds of operation.[351]

The committee noted that the average speed of a real-world cycle implies the level to which the cycle includes transient speed behavior – very low speed cycles have high idle content.[352] The committee also noted that in the same way, values such as "stops per unit distance," average instantaneous acceleration or deceleration, and coefficient of variance of speed become smaller as average speed rises.[353] The committee stated that because vehicles in the real world do not operate at steady speed, it is important for a cycle to use the metric of average speed in discussing fuel use.[354] Trucks operating at high average speed on freeways tend to be driven at a sustained, fairly steady speed, but trucks operating at lower speed in suburban or urban environments (or on congested freeways) tend to vary their speed substantially, and urban activity is associated with frequent stops.[355] The committee stated that the effect of the increased transient behavior at low speeds is to raise the quantity of fuel consumed at low speeds, mainly due to the wasting of energy with service brakes and the associated need for propulsion energy during the next acceleration event.[356] Thus, the committee was very aware of the impact of vehicle design, functionality, use, and duty cycle on MHDV fuel efficiency, and stressed the need for a regulatory program to consider these issues

[347] Id.
[348] Id.
[349] Id.
[350] Id.
[351] Id. The committee also noted a number of duty cycles that have been developed for vocational truck and bus behavior, including, among others, an NREL-developed refuse truck cycle, a cycle for Class 4 and 6 Parcel Delivery Trucks developed by the Hybrid Truck Users Forum, and bus cycles developed by the Manhattan and Orange County Transit Authority (OCTA) and by the Washington Metropolitan Area Transit Authority. *See* Id. at 31-32.
[352] Id. at 32.
[353] Id.
[354] Id. at 34.
[355] Id.
[356] Id. at 35.

carefully in setting standards and developing duty cycles appropriate for compliance testing.

Infrastructure:

The NAS committee addressed a couple of different overarching infrastructure issues that could affect MHDV fuel efficiency. First, there is the issue of whether infrastructure exists, and how much infrastructure is needed, to support MHDV electrification technologies. Technologies like plug-in hybrid electric vehiclepowertrains can significantly improve vehicle fuel efficiency for some applications, but if grid-connected charging points are not available, their utility is more limited. Second, there is the issue of how freight can be moved most efficiently, which can be affected by vehicle size and weight limits, ITS, the existence or construction of exclusive truck lanes, and intermodal infrastructure. The NAS committee may have considered other infrastructure-related issues in its report, but these seemed most directly pertinent to MHDV fuel efficiency, and we therefore summarize them below.

Infrastructure for vehicle electrification:

The committee noted that PHEV technology can be applied to a wide variety of MD/HD vehicles, citing the example of a Ford F-550 "trouble" truck platform developed by Eaton Corporation, Ford, and the Electric Power Research Institute (EPRI) used to repair and maintain the transmission and distribution infrastructure of utilities.[357] The committee stated that by using grid electricity stored in batteries for part of the vehicle's daily duty cycle, the plug-in vehicle can operate at the job site for several hours continuously, running the bucket, power tools, lights, and accessories without the need to run the gasoline or diesel engine.[358] The committee suggested that one of the most important ways of maximizing the effectiveness of PHEV technology is to combine it with intelligent vehicle technologies, so that the vehicle can anticipate demands for speed, acceleration, and distance, and switch between the gasoline engine and the battery accordingly.[359] Thus, in order to maximize the fuel efficiency improvements possible due to PHEV MHDV applications, both grid-electricity charging points and intelligent vehicle technology systems need to be developed and available.

The committee also provided the example of combination tractor "hoteling" as one in which PHEV technology could be useful, because in existing vehicles, the engine is running for the entire 8 or so hours in order to operate the A/C, heat, and on-board appliances, and to keep the fuel warm in cold weather.[360] The committee stated that while hybrids in general aim to eliminate idling altogether, a PHEV (or a regular HEV) can run the engine at a specified and efficient power range solely for the purpose of storing energy in the battery packs.[361] The engine can then be switched on and off as the

[357] Id. at 74.
[358] Id.
[359] Id.
[360] Id.
[361] Id.

state-of-charge requires.[362] The committee stated that for PHEVs, these hotel loads can be powered with grid electricity at rest stops, if the required infrastructure (i.e., electrified parking spaces) is in place.[363] The committee noted that there are currently 138 truck stops with electrified parking spaces in 34 States, which allow truckers to hotel their vehicles using grid electricity.[364] However, the committee emphasized that as discussed in the NRC's review of the DOE 21st Century Truck Partnership, continuing efforts are needed to standardize the electrical systems on trucks and at truck stops.[365]

Infrastructure for moving freight efficiently:

Moving freight more efficiently refers to moving the same amount of freight while using less energy or fuel, or to moving more freight while using the same amount or less energy or fuel. There are a number of ways that have been considered to move freight more efficiently, many of which could require changes to infrastructure in order to implement.

Improvements to road and bridge infrastructure could allow increases in truck size and weight limits and construction of exclusive truck lanes. The NAS committee recommended that Congress give serious consideration to liberalizing weight and size restrictions for combination tractors and trailers[366] – vehicles that can carry more (both weight and volume) are inherently more efficient because fewer trips need to be taken. The committee stated that a high percentage of trucks on the road at any time are empty or are loaded to less than either their weight or their volumetric capacity limit, but that if all loaded trucks carried the maximum legal payload weight at all times, the reduction in vehicles-miles of truck travel would be inversely proportional to the increase in payload.[367] The committee noted that part of the original reason for size and weight limits for trucks related to the need to standardize design parameters for road construction (such as bridge strength, road curve radii, etc.), while current rationales in favor of limits focus on safety concerns.[368] The committee recognized that the literature did not conclusively support liberalization of size and weight limits as a way to improve fuel efficiency definitively, but pointed to a 2002 TRB committee finding that properly designed revisions to limits would yield freight cost savings exceeding any added extra infrastructure costs.[369] The TRB report stated that truck fees would have to be adjusted, if size and weight restrictions were liberalized, to cover highway agency costs, improved bridge management, systematic monitoring of truck traffic, reform of enforcement methods, and vehicle safety regulations governing the performance of larger trucks.[370]

[362] Id.
[363] Id.
[364] Id. at 123.
[365] Id.
[366] Id. at 177, Recommendation 7-2.
[367] Id. at 164.
[368] Id.
[369] Id. at 165.
[370] Id. at 166.

The committee identified construction of new exclusive lanes for larger trucks as one of the more ambitious proposals for infrastructure changes to improve truck fuel efficiency.[371] There are several types of designs for truck-only lanes, including using the inside two lanes in each direction on interstate highways for trucks only; the placement of truck-only lanes *over* the current auto traffic lanes; and the construction of underground tunnels for trucks to take them out of the main traffic flow.[372] The committee noted that several State transportation departments had studied the potential construction of truck-only lanes, but to date none had been constructed for the purpose of moving only truck traffic for any long distances.[373] The committee stated that some of the advantages of creating such additional infrastructure would be that freight could be moved faster and more efficiently if lanes can be specifically built to accommodate heavier loads, and that congestion could be reduced if the truck-only lanes and staging areas are carefully designed.[374] However, the committee also stated that creating truck-only lanes would be expensive and time-consuming, and the social return on investment in truck-only lanes had not yet been established.[375] The committee also noted the need to purchase adequate rights-of-way for the construction, with potential negative environmental consequences.[376]

The committee also considered the extent to which ITS could help monitor and manage traffic flow, reduce congestion, provide alternate routes to travelers, and enhance productivity when integrated into the transportation system infrastructure.[377] Stressing that ITS is very broad in scope, the committee focused on technologies and applications of ITS in the infrastructure that help reduce the bottlenecks that truckers often experience – namely, congestion, toll booths, weigh stations, and inspection stations.[378] Some examples of potential technology solutions identified by the committee include

- Real-time traffic information (from imbedded inductive loop detectors in the highways or from traffic probe vehicles with special cell phones to convey vehicle position and velocity to a centralized location) provided to travelers via dynamic message signs or highway advisory ratio while en route;[379]
- Adaptive traffic signal control and coordinated signal timing;[380]
- Ramp control (such as ramp meters that use sensor data to optimize freeway travel speeds and ramp wait times);[381]
- Electronic toll collection (ETC) systems such as EZ-Pass, where vehicles are identified and charged via an in-vehicle transponder to allow toll transactions to

[371] Id. at 171.
[372] Id.
[373] Id.
[374] Id.
[375] Id. at 172.
[376] Id.
[377] Id. at 168.
[378] Id. at 169.
[379] Id.
[380] Id.
[381] Id.

be processed at freeway speeds rather than requiring the significant slow-down and idling that can happen in traditional toll systems;[382] and

- Roadside communications equipment that can screen in-vehicle transponders to check for safety, border clearance, weight, and credentials.[383]

All of these have the potential to improve MHDV fuel efficiency by keeping vehicles moving at optimum speeds and reducing time spent at slower, less efficient speeds or idling. The committee found few known disadvantages with implementing these technologies, but cited a number of implementation issues associated with ITS that could make its widespread deployment more difficult, including the need for multi-jurisdictional cooperation in setting up ITS; making ITS compatible with each other and with existing systems; protecting ITS deployments in remote locations and ensuring that adequate power is available for them; and privacy issues with respect to driver concerns about government surveillance.[384]

And finally, the committee discussed the potential for intermodal shifts in freight to improve efficiency on a ton-mile basis. The committee stated that because rail and ship are significantly less energy-intensive than trucks, incentivizing the movement of goods from trucks to rail or ship is one way to improve the overall efficiency of the freight transportation system.[385] The committee stressed that attempting to estimate fuel efficiency improvements due to intermodal shifting is difficult due to the complex nature of competition between trucks and rail; the limitations on mode shifting given that only certain types of commodities are really suited for rail shipping; and that market demand for rail shipping both affects and is dependent on the quality of rail service.[386]

The committee noted that significant investment in rights-of-way, in rolling stock, and in overcoming infrastructure-induced capacity constraints would need to be made over a long time period before intermodal shifting could be extensive, and that freight delivery service and performance could be sacrificed in the shift.[387] The committee emphasized that the investment should be justified based on the overall economics of the investment in the delivery system, and not just the fuel consumption savings that would result from diversion of freight from truck to rail. However, the committee stated that in some transport corridors where economically sound investments can be undertaken – like in the mid-Atlantic region – there are fuel savings to be realized.[388] The committee suggested that rail diversion could be promoted by facilitating the construction of freight "villages," that include intermodal terminals, transload facilities, and bulk storage facilities; expanded market reach for regional railroads; and continued improvement in rail infrastructure, including signal, track, bridge, terminal, and clearance upgrades.[389] Nevertheless, the committee noted that most of the easier rail capacity improvement

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[382] Id.
[383] Id.
[384] Id. at 170-171.
[385] Id. at 175.
[386] Id.
[387] Id. at 176.
[388] Id. at 175-176.
[389] Id. at 176.

projects have already been built, leaving government to incentivize the more challenging ones.[390]

Total overall energy consumption and operating cost – the rebound effect:

The NAS committee considered the rebound effect in the context of indirect effects and externalities that could occur as a result of regulating MHDV fuel efficiency, that the committee started NHTSA should address in order to avoid unintended consequences. The committee noted that if truck operating costs fall due to the regulations that promote fuel efficiency, freight rates may fall in the short run, and as a result truck freight volume may increase, due to diversion from other transportation modes such as rail or barge.[391] In the long run, the committee stated, lower freight rates could affect entire logistics networks, thus affecting the location of distribution centers and warehouses.[392]

On the other hand, the committee noted that if the application of technology in response to fuel efficiency standards pushes beyond the private cost-effective level, causing the costs of shipping to increase, the response will be the reverse of the rebound effect, as higher costs lead to fewer shipments of freight by truck.[393] The committee stated that such a case could nevertheless be socially efficient if the higher cost is truly reflecting the additional social costs of climate change and oil security due to fuel consumption, because the goal of the standard would be to push technology adoption to the point at which those externalities are internalized by the industry.[394]

The committee stated that the impact of freight prices on VMT can be measured using truck freight's own-price elasticity.[395] The own-price elasticity is a measure of how much the quantity of a product demanded changes in response to a change in the price of the product.[396] An associated concept is the cross-price elasticity that measures the impact on quantity demanded of a good based on a change in price of a substitute good.[397] The committee examined a number of studies measuring own-price and cost-price elasticities for long-haul freight movements, and found that their results varied widely, depending on the type of product being shipped, the geography of the shipments, trip lengths, and the specific functional form used to describe the relationship.[398] The committee emphasized that the rebound effect has been much less studied for MD/HD vehicles compared to in the light-duty context, and that given the wide range of results for freight demand elasticities studies – anywhere from -0.5 to -1.5 for own-price

[390] Id.
[391] Id. at 151.
[392] Id.
[393] Id.
[394] Id.
[395] Id.
[396] Id.
[397] Id.
[398] Id.

elasticity and from 0.35 to 0.59 for cross-price elasticity – the committee did not believe it was possible for it to provide a confident measure of the rebound effect.[399]

2. What does NHTSA think could affect MHDV fuel efficiency?

Design, functionality, use, and duty cycle:

NHTSA and EPA recognize that the heavy-duty sector is extremely diverse in several respects, including types of manufacturing companies involved, the range of sizes of trucks and engines they produce, the types of work the trucks are designed to perform, and the regulatory history of different subcategories of vehicles and engines. The current heavy-duty fleet encompasses vehicles from the "18-wheeler" combination trucks one sees on the highway to school and transit buses, to vocational vehicles such as utility service trucks, as well as the largest pickup trucks and vans. In light of the industry's diversity, as noted by the NAS committee, the agencies are proposing an HD National Program in the NPRM accompanying this study that recognizes the different sizes and work requirements of this wide range of heavy-duty vehicles and their engines. NHTSA's proposed fuel consumption standards and EPA's proposed GHG standards would apply, as discussed above, to manufacturers of the following types of heavy-duty vehicles and their engines: (1) heavy-duty pickup trucks and vans; (2) combination tractors; and (3) vocational trucks. Some categories of vehicles are further subdivided into multiple standards for different vehicles – for example, there are seven standards for combination tractors depending on their configuration and use – to better capture the impact that design and use have on a vehicle's fuel efficiency capability.

Consistent with this approach of recognizing differences in how vehicle design, functionality, and use affect vehicle fuel efficiency, the duty cycles being proposed by the agencies in the NPRM accompanying this study vary for the different categories being regulated.

HD Pickup Truck and Van Duty Cycles:

For HD pickup trucks and vans, the agencies are proposing to require complete vehicles to be tested using the Federal Test Procedure (FTP) and the Highway Fuel Economy Test (HFET) currently required for criteria emissions certification, as well as for CAFE/GHG emissions standards compliance for light-duty vehicles. Previously, complete vehicles (such as HD pickups and vans) with a gross vehicle weight rating of 8,500-14,000 pounds could be certified according to 40 CFR part 86, section S. These heavy-duty chassis certified vehicles were required to pass emissions on both the FTP and HFET. In the NPRM accompanying this study, the agencies propose to use those same testing procedures that already required for certification to EPA's criteria emissions standards. Using the data from these two tests, EPA could apply attribute-based standards for CO_2 emissions, and NHTSA could extrapolate that data to apply attribute-based standards for fuel consumption.

[399] Id. at 152.

HD Engine Duty Cycles:

For HD Engines, under EPA's current criteria emissions regulations for engines, manufacturers are required to demonstrate compliance using two test methods: the heavy-duty transient cycle, and the heavy-duty steady-state test. Each test is an engine speed versus engine torque schedule that is intended to be run on an engine dynamometer. Over each test, emissions are sampled using the equipment and procedures outlined in 40 CFR Part 1065, which includes provisions for measuring CO_2, N_2O, and CH_4. Emissions may be sampled continuously or in a batch configuration (commonly known as "bag sampling") and the total mass of emissions over each cycle are normalized by the engine power required to complete the cycle. Following each test, a validation check is made comparing actual engine speed and torque over the cycle to the commanded values. If these values do not align well, the test is deemed invalid. The transient test, also known as the Federal Test Procedure (FTP), is characteristic of typical urban stop-and-go driving, and also includes a period of more steady-state operation that would be typical of short cruise intervals at 45 to 55 miles per hour. Each transient test consists of two 20-minute tests separated by a "soak" period of 20 minutes. The first test is run with the engine in a "cold" state, which involves letting the engine cool to ambient conditions either by sitting overnight or by forced cooling provisions outlined in § 86.1335-90 (or 40 CFR Part 1036). This portion of the test is meant to assess the ability of the engine to control emissions during the period prior to reaching normal operating temperature. This is commonly a challenging area in criteria pollutant emission control, as cold combustion chamber surfaces tend to inhibit mixing and vaporization of fuel and after-treatment devices do not tend to function well at low temperatures.

Following the first test, the engine is shut off for a period of 20 minutes, during which emission analyzer checks are performed and preparations are made for the second test (also known as the "hot" test). After completion of the second test, the results from the cold and hot tests are weighted and a single composite result is calculated for each pollutant. Based on typical in-use duty cycles, the cold test results are given a 1/7 weighting and the hot test results are given a 6/7 weighting. Deterioration factors are applied to the final weighted results and the results are then compared to the emission standards.

Prior to 2007, criteria emissions standards compliance only needed to be demonstrated by engine manufacturers over the FTP. However, a number of events brought to light the fact that this transient cycle may not be as well suited for engines that spend much of their duty cycle at steady cruise conditions, such as those used in line-haul semi-trucks. As a result, EPA added the steady-state test, which was known as the supplemental emission test (or SET), and consisted of 13 steady-state modes. During each mode, emissions were sampled for a period of five minutes. Weighting factors were then applied to each mode and the final weighted results were compared to the emission standards (including deterioration factors). Emissions at each mode could not exceed the NTE emission limits. Alternatively, manufacturers could run the test as a "ramped-modal cycle" (RMC). In this case, the cycle still consists of the same speed/torque modes, but linear progressions between points are added, and instead of weighting factors, each mode is sampled for various amounts of time. The result is a continuous cycle lasting approximately 40 minutes. With the implementation of Part 1065 test procedures in 2010, manufacturers are now required to run the modal test as a ramped-modal cycle. In addition, the order of the speed/torque modes in the RMC have changed for 2010 and later engines.

As the NAS committee recognized, it is well known that fuel consumption, and therefore CO_2 emissions, are highly dependent on the drive cycle over which they are measured. Steady cruise conditions, such as highway driving, tend to be more efficient, having lower fuel consumption and CO_2 emissions. In contrast, highly transient operation, such as city driving, tends to lead to lower efficiency and therefore higher fuel consumption and CO_2 emissions.

For the heavy-duty engine and vehicle standards being proposed in the NPRM accompanying this study, the agencies believe that it is important to assess CO_2 emissions and fuel consumption over both transient and steady-state test cycles, as all vehicles will operate in conditions typical of each cycle at some point in their useful life. However, due to the drive cycle dependence of CO_2 emissions, we do not believe it is reasonable to have a single CO_2 standard that must be met for both cycles. A single CO_2 standard seems likely prove to be too lax for steady-state conditions, while being too strict for transient conditions.

To address this concern, in the NPRM accompanying this study, the agencies are proposing to require that all heavy-duty engines be tested over both transient and steady-state tests. However, only the results from either the transient or steady-state test cycles will be used to assess compliance with the fuel consumption and GHG standards, depending on the type of vehicle in which the engine will be used. Thus, engines that will be used in Class 7/8 tractors will use the RMC for fuel consumption and GHG certification, while engines that will be used in vocational vehicles will use the FTP transient test. In both cases, results from the other test cycle will still be reported, but will not be used for a compliance decision.

<u>Combination Tractor Duty Cycles</u>:

In the NPRM accompanying this study, the agencies are proposing to require combination tractors to be tested over three test cycles – one transient and two steady-state. For the transient test, we are proposing to use the heavy-heavy-duty diesel truck (HHDDT) transient test cycle, which was developed by the California Air Resources Board and West Virginia University to evaluate heavy-duty vehicles. This transient mode simulates urban start-stop driving, featuring 1.8 stops per mile over the 2.9 mile duration. The two steady-state test points are meant to reflect the tendency for some of these vehicles to operate for extended periods at highway speeds. Based on data from the EPA's Motor Vehicle Emission Simulator database and common highway speed limits, the agencies have established these two points at 55 and 65 mph.

The Greenhouse gas Emissions Model (GEM) proposed by the agencies for determining vehicle compliance will predict the total emissions results from each regulatory subcategory (e.g., "LHD Vocational Vehicle," or "Class 8 Low Roof Sleeper Cab Tractor") using the unique properties entered by the manufacturer for each vehicle. These inputs are then run according to the defined test payload and distance covered, so as to yield a gram/ton-mile result, as well as a fuel consumption (gal/ton-mile) result for each test cycle. As with engine testing, certification will be based on a parent rating for the test group, representing the worst-case fuel consumption and CO_2 emissions, but vehicle manufacturers will also have the opportunity to model sub-configurations to determine any benefits that are available on only a select number of vehicles within a test group.

The results from all three tests would then be combined using weighting factors reflecting typical usage patterns. The typical usage characteristics of Class 7 and 8 trucks with day cabs differ significantly from Class 8 vehicles with sleeper cabs: the trucks with day cabs tend to operate in more urban areas, to have a limited travel range, and to return to a common depot at the end of each shift; while Class 8 sleeper cabs are typically used for long distance trips, consisting of mostly highway driving, in an effort to cover the highest mileage in the shortest time. For these reasons, in the NPRM accompanying this study, the agencies are proposing that the transient and steady-state cycles be weighted differently for these two groups of vehicles. For Class 7 and 8 trucks with day cabs, the agencies are proposing to weight the 65-mph steady-state test by 64 percent, the 55-mph steady-state test by 17 percent, and the transient test by 19 percent. For Class 8 with sleeper cabs, in contrast, due to their tendency to spend the majority of their time at high-speed cruise, the agencies are proposing to weight the 65-mph steady-state test by 86 percent, the 55-mph steady-state test by 9 percent, and the transient test by 5 percent. The final, weighted emission results would be compared to the fuel consumption and emission standards to assess compliance.

Vocational Truck Duty Cycles:

In the NPRM accompanying this study, demonstrating compliance for vocational vehicles with the fuel consumption and GHG standards, at least for this first phase of the HD National Program, primarily involves demonstrating the use of low rolling resistance tires and quantifying the associated fuel consumption/CO_2 benefit. Similar to Class 7/8 combination tractors, the agencies are proposing that manufacturers will demonstrate compliance with the standards using GEM. However, the input parameters that can be entered by the vehicle manufacturer will be limited to the properties of the tires – GEM will generate a complete vehicle model using that tire data along with a representative baseline truck and engine. The test weight employed by the model will be based on the vehicle class – light-heavy duty vehicles will have an assigned test weight of 16,000 lbs; medium-heavy duty vehicles will have an assigned test weight of 25,150 lbs; and heavy-heavy duty vocational vehicles will have an assigned test weight of 67,000 lbs. The model will then be exercised over three test cycles – the HHDDT transient cycle, as well as 55- and 65-mph steady-state cruise conditions. The results of each of the three tests would be weighted at 37 percent for the 65-mph steady-state cycle, 21 percent for the 55-mph steady-state cycle, and 42 percent for the transient cycle.

The agencies recognize that for this first phase of the HD National Program, it may seem more expedient and just as accurate simply to require that manufacturers use tires meeting certain industry standards for qualifying tires as having low rolling resistance. CO_2 and fuel consumption benefits could then simply be quantified for different ranges of coefficients of rolling resistance to provide a means for comparison to the standard. However, the agencies believe that as technology advances, other aspects of vocational vehicles besides low rolling resistance tires may warrant inclusion in future rulemakings. For this reason, we believe it is important to have the certification framework in place to accommodate such additions. The modeling approach for this phase of the rules thus serves to create a certification pathway for future rulemakings, which we believe is a reasonable approach.

Duty Cycles to Be Used for Obtaining Hybrid Credits:

In the NPRM accompanying this study, the agencies are proposing two sets of duty cycles to evaluate the benefit depending on the vehicle application (such as delivery trucks, as compared to bucket trucks or refuse trucks) to assess hybrid vehicle performance. The key difference between these two sets of vehicles is that one set (such as delivery trucks) does not employ a PTO unit as part of its operation, while the other set (such as bucket and refuse applications) does.

The first set of duty cycles to assess emissions and fuel consumption improvements due to hybrid technology would apply to the hybrid powertrains used only to improve the motive performance of the vehicle, such as hybrids used on pickup and delivery trucks). The typical operation of these vehicles is very similar to the overall drive cycles being proposed for vocational vehicles, so the agencies are proposing to use the same vocational vehicle weightings for these vehicles, as shown in the table below. If a manufacturer wishes to use hybrid or innovative vehicles for other sectors, improvements associated with hybrid technology will be assessed using traditional duty cycle and test procedures for conventional vehicles.

When employed in applications such as utility and refuse trucks, hybrid powertrains tend to have additional benefit associated with use of stored energy, which avoids main engine operation and related CO_2 emissions and fuel consumption. To appropriately address these alternative sources for benefits, exercising the conventional and hybrid vehicles using their PTO would help to capture the benefit to GHG emissions and fuel consumption reductions. The second set of duty cycles proposed to quantify the hybrid CO_2 and fuel consumption impact over this broader set of operations would be the three primary cycles plus a PTO duty cycle. The proposed PTO cycle is based on consideration of using alternate, appropriate duty cycles with EPA Administrator approval in a public process. The PTO individual drive cycle weighting percentages are intended to reflect typical use, driving patterns and sales mix of utility trucks and refuse haulers. The proposed weightings for the hybrids with PTO are included in the table below.

Table III.D.1: Proposed Drive Cycle Weightings for Hybrid Vehicles

	Transient	55 mph	65 mph	PTO
Vocational Vehicles without PTO	42%	21%	37%	0%
Vocational Vehicles with PTO	30%	15%	27%	28%

Infrastructure:

NHTSA agrees with the NAS committee that investment in infrastructure has the potential to improve MHDV fuel efficiency, but that there are a number of different challenges to overcome depending on whether the issue is infrastructure to support MHDV electrification technologies or infrastructure to support the efficient movement of freight through changes or improvements in vehicle size and weight limits, ITS, the existence or construction of exclusive truck lanes, and intermodal infrastructure.

For the reader's reference, we note that DOT currently has a dedicated effort underway to implement intelligent transportation systems.[400] The IntelliDrive program is a major initiative of the ITS Joint Programs Office at DOT's Research and Innovative Technology Administration. (*Intellidrive* is a servicemark of the Department of Transportation.) Specifically, DOT's IntelliDrive program is focused on advancing connectivity among vehicles and roadway infrastructure in order to significantly improve the safety and mobility of the U.S. transportation system. The program is working toward a future vision where vehicles and infrastructure are connected to enable crashless vehicles, and access to real-time data on the status of both vehicles and the roadway transforms transportation system management and operations to dramatically improve performance.

In terms of fuel efficiency improvements, the IntelliDrive (effort aims at providing travelers with real-time information about traffic congestion and other travel conditions helps them make more informed decisions that can reduce the environmental impact of their trip. Informed travelers may decide to avoid congestion by taking alternate routes or public transit, or by rescheduling their trip – all of which can make their trip more fuel-efficient and eco-friendly. The ability for vehicles to "talk to" the infrastructure could provide information to the vehicle operator so that he/she can drive through a traffic signal network at optimum speeds to reduce stopping. Many transportation management activities that enhance mobility, by reducing vehicle idling due to traffic congestion, also potentially reduce emissions.

IntelliDrive is being developed through coordinated research, testing, demonstration and deployment. The Federal research investment is targeted to areas that are unlikely to be accomplished through private investment because they are too risky or complex. Other stakeholders, including the States, the automotive industry and their

[400] More information is available at http://www.intellidriveusa.org/ (last accessed Sept. 20, 2010).

suppliers, and consumer electronics companies, also are researching and testing IntelliDrive technologies and applications so that the transportation community can realize the full potential and vision of IntelliDrive.

We also note that the Federal Highway Administration (FHWA) currently coordinates the Intermodal Freight Technology Working Group (IFTWG) to evaluate and promote intermodal transport opportunities.[401] This working group is a public-private partnership focused on the identification and evaluation of technology-based options for improving the efficiency, safety, and security of intermodal freight movement. Working from this common goal, the IFTWG engages in efforts to marry industry and government priorities in a way that leverages collective experience and shared investment.

However, we finally note that the infrastructure issues discussed by the committee are generally outside NHTSA's authority to control, as the committee recognized. NHTSA intends to monitor these issues as the proposed HD National Program is implemented, and will consider changing its regulatory approach as appropriate to facilitate maximum fuel efficiency improvements if greater coordination with infrastructure-related solutions is possible.

Total overall energy consumption and operating cost – the rebound effect:

NHTSA agrees with the NAS committee that estimating the rebound effect for MD/HD vehicles is a different exercise than estimating it for light-duty vehicles, and that furtheranalysis will be necessary to establish its value.

To begin examining this issue, NHTSA reviewed the work of Cambridge Systematics, Inc. (CSI) that was commissioned by the NAS committee.[402] The CSI analysis evaluated two scenarios of fuel economy standards and associated cost increases for Class 8 combination tractors. The first scenario relied upon an estimate that the fuel economy of combination tractors could be increased from its current average of 5.59 mpg to 6.80 mpg at an additional incremental cost of $22,930 per vehicle, while the second scenario estimated that their average fuel economy could be increased from 5.59 to 9.1 mpg at an incremental cost of $71,630 per vehicle.[403]

The CSI analysis converted these estimates to changes in ownership and operating costs for combination trucks, and in turn to equivalent changes in the rates that their operators would charge for freight shipping, under the assumption that the resulting changes in truck ownership and operating costs would be fully reflected in truck shipping rates. On balance, the CSI analysis estimated that the decline in fuel costs would more

[401] More information is available at http://ops.fhwa.dot.gov/freight/intermodal/iftwg.htm (last accessed Sept. 20, 2010).
[402] Cambridge Systematics, Inc., *Assessment of Fuel Economy Technologies for Medium and Heavy Duty Vehicles: Commissioned Paper on Indirect Costs and Alternative Approaches*, Draft, September 17, 2009.
[403] CSI derived these estimates of potential increases in combination truck fuel economy and the costs of achieving them from information reported in Northeast States Center for a Clean Air Future, Southeast Research Institute, TIAX, LLC., and International Council on Clean Transportation, *Reducing Heavy-Duty Long Haul Truck Fuel Consumption and* CO_2 *Emissions*, September 2009.

than offset the increase in truck ownership costs, and that truck shipping rates would decline by 4.6 percent in the first scenario and by 6.9 percent in the second scenario.

Next, the CSI analysis applied estimates of the "own-price" and "cross-price" elasticities of demand for truck and rail shipping with respect to trucking rates drawn from published research to these changes in trucking rates, in order to estimate the increase in freight shipping by truck that would occur. The analysis considered two potential sources of increased truck shipping in response to lower shipping rates: (1) increases in the distribution and purchases of commodities presently shipped by truck, as their delivered prices decline to reflect lower shipping rates; and (2) shifts of some shipments that are presently carried by rail to truck as trucking rates decline relative to those for rail freight. The own-price elasticities of demand for truck shipping with respect to trucking rates used in the analysis ranged from -0.5 to -1.5, while the cross-price elasticities of demand for rail shipments with respect to trucking rates ranged from 0.35 to 0.59. Finally, the estimated increases in truck shipping activity were assumed to be translated directly into truck usage and fuel consumption, using the improved fuel economy levels for combination trucks that were estimated to occur under each scenario.

The resulting calculations, which also employed a number of simplifying assumptions, produced two estimates of the fuel economy rebound effect for combination trucks. The fuel economy rebound effect measures the fraction of fuel savings that would otherwise be expected to result from an increase in fuel economy, but is offset by increased use of vehicles whose fuel economy is improved. The first estimate, termed the "First Rebound Effect," included only the increase in truck fuel consumption resulting from increases in the distribution and sale of commodities presently shipped by truck (source 1 above), while the second estimate (or "Second Rebound Effect") deducted the savings in fuel consumption for shipping by rail that was assumed to occur as some shipments were diverted from rail to truck (source 2 above). As a consequence, the first estimate of the rebound effect was larger in magnitude than the second. Both estimates were included in the analysis because of uncertainty regarding the extent to which offsetting fuel savings in rail freight shipping would actually be achieved as some freight shipments were diverted to trucks.

Table III.D.2 below reports the estimates of the fuel economy rebound effect for combination trucks derived in the CSI study.

Table III.D.2: Range of Rebound Effect Estimates From CSI's Aggregate Assessment

Source of Estimate	Scenario 1 (6.8 mpg, $22,930)	Scenario 2 (9.1 mpg, $71,630)
"First Rebound Effect" (increase in truck VMT resulting from decrease in operating costs)	11-31%	5-16%
"Second Rebound Effect" (net fuel savings when decreases in rail fuel consumption are taken into account)	9-13 %	3-15%

CSI included a number of caveats associated with these estimates. First, CSI stated that the elasticity estimates derived from the literature are "heavily reliant on factors including the type of demand measures analyzed (vehicle-miles of travel, ton-miles, or tons), analysis geography, trip lengths, markets served, and commodities transported."[404] Second, CSI emphasized that its example only focused on Class 8 combination tractors, and did not attempt to quantify the potential rebound effect for any other truck classes. Finally, CSI stressed that these scenarios should be characterized as "sketches," rather than as precise numerical estimates. Given these caveats, the CSI estimates were not included in the final NAS report.

Recognizing the caveats with the CSI study, as an alternative, NHTSA used an econometric approach to estimate the rebound effect for both single-unit (approximately Class 4-7) trucks and combination tractors (Class 8). As shown in Table III.D.3 below, the estimates for the long-run rebound effect are larger than the estimates in the short-run, which is consistent with the theory recognized by the NAS committee that shippers have more flexibility to change their behavior (e.g., to restructure contracts or logistics) if given more time.[405] As the table indicates, the rebound effect estimates derived by NHTSA from national data on truck use and fuel costs were larger in magnitude than those derived from State data.[406] One possible explanation for the difference in the estimates is that the national rebound estimates are capturing some impacts of changes in economic activity that often accompany rapid or wide variations in fuel prices. Historically, large increases in fuel prices are highly correlated with economic downturns, and there may not be enough independent variation between fuel prices and macroeconomic activity in the national data to reliably differentiate the impact of fuel price changes from changes in economic activity. In contrast, some states may see an increase in economic output when energy prices increase (e.g., large oil producing States such as Texas and Alaska), and therefore the State data may be more accurately isolating the individual impact of fuel price changes.

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[404] Cambridge Systematics, Inc,, pp, 8-9.

[405] The results of NHTSA's analysis indicated that there was no significant difference between the short- and long-run rebound effects for combination trucks; the full magnitude of the estimated rebound effect is reached within one year of a change in fuel prices or fuel economy.

[406] NHTSA's estimates of the rebound effect are derived from econometric analysis of national and State VMT data reported in Federal Highway Administration, *Highway Statistics*, various editions, Tables VM-1 and VM-4. Specifically, the estimates of the rebound effect reported in Table III.D.3 are ranges of the estimated short-run and long-run elasticities of annual VMT by single-unit and combination trucks with respect to fuel cost per mile driven. (Fuel cost per mile driven during each year is equal to average fuel price per gallon during that year divided by average fuel economy of the truck fleet during that same year.) These estimates are derived from time-series regression of annual national aggregate VMT for the period 1970-2008 on measures of nationwide economic activity, including aggregate GDP, the value of durable and nondurable goods production, and the volume of U.S. exports and imports of goods, and variables affecting the price of trucking services (driver wage rates, truck purchase prices, and fuel costs), and from regression of VMT for each individual State over the period 1994-2008 on similar variables measured at the State level.

Table III.D.3: Range of Rebound Effect Estimates From NHTSA Econometric Analysis

Truck Type	National Data		State Data	
	Short Run	Long Run	Short Run	Long Run
Single Unit	13-22%	28-45%	3-8%	12-21%
Combination	12-14%		4-5%	

NHTSA recognizes that there are multiple methodologies for quantifying the rebound effect, and that these different methodologies produce a wide range of potential estimates of its magnitude. However, for the purposes of quantifying the rebound effect for the NPRM accompanying this study, NHTSA chose a rebound effect with respect to changes in fuel costs per mile in the lower range of the long-run estimates reported above. The agency also relied more heavily upon the estimates derived from State-level data on truck usage and fuel costs than on the corresponding national data. Given the fact that the long-run State estimates are generally more consistent with the aggregate estimates, NHTSA chose a rebound effect for single-unit trucks of 15 percent, which is within the range of estimates from both methodologies examined. Similarly, NHTSA has chosen a rebound effect for combination tractors of 5 percent.

To date, no estimates of the rebound effect for Class 2b and 3 trucks (which make up the majority of HD pickups and vans) have been cited in the literature. Since these particular vehicles are used for very different purposes than other heavy-duty vehicles, it does not necessarily seem appropriate to apply one of the estimates above to the Class 2b and 3 vehicles. Class 2b and 3 vehicles are more similar in use to large light-duty vehicles, so for the purposes of our analysis of the NPRM accompanying this study, NHTSA chose to apply its previous estimate of the light-duty rebound effect, which is 10 percent, to this class of vehicles.[407]

We note that NHTSA has not attempted to take into account any potential fuel savings or GHG emission reductions from the rail sector due to mode shifting. NHTSA elected not to include any offsetting reductions in rail fuel consumption in its estimates because of uncertainty about whether reductions in rail service and accompanying fuel use would actually occur in response to the diversion of a small fraction of freight shipments from rail to truck. For some idea of how such mode shifting could affect the estimates of fuel savings and the resulting magnitude of the rebound effect, the reader can refer to CSI's example calculations in their report.

We also note that NHTSA has a number of simplifying assumptions in our calculations, which are discussed in more detail in Chapter 6 of the DRIA accompanying this study and the NPRM. Specifically, NHTSA did not attempt to capture how current market failures might impact the rebound effect. The direction and magnitude of the rebound effect in the heavy-duty truck market are expected to vary depending on the existence and types of market failures affecting the fuel economy of the trucking fleet and

[407] *See* 74 Fed. Reg. 49454, 49671-72 (Sept. 28, 2009) and 75 Fed. Reg. 25324, 25379 (May 7, 2010).

depending on the segment of the fleet in question. For example, if firms are already accurately accounting for the costs and benefits of these technologies and fuel savings, then these regulations would increase their net costs, because trucks would already include all the cost-effective technologies. As a result, the estimated rebound effect would actually be *negative*, and truck VMT would decrease as a result of these proposed regulations.

In contrast, if firms are not optimizing their behavior today due to factors such as lack of reliable information, it is more likely that truck VMT would increase. If firms recognize their lower net costs as a result of these regulations and pass those costs along to their customers, then the rebound effect would increase truck VMT. This response assumes that trucking rates include both truck purchase costs and fuel costs, and that the truck purchase costs included in the rates spread those costs over the full expected lifetime of the trucks. If those costs are spread over a shorter period, as the expected short payback period implies, then those purchase costs will inhibit reduction of freight rates, and the rebound effect will be correspondingly smaller.

If there are market failures such as split incentives, estimating the rebound effect may depend on the nature of the failures. For example, if the original purchaser cannot fully recoup the higher upfront costs through fuel savings before selling the vehicle nor pass those costs onto the resale buyer, the firm would be expected to raise shipping rates to compensate. A firm purchasing the truck second-hand might reduce shipping rates if the firm recognizes the cost savings after operating the vehicle, thus leading to an increase in VMT. Similarly, if there are split incentives and the vehicle buyer is a different entity from the one that purchases the fuel, than there would theoretically be a positive rebound effect, because fuel savings would lower the net costs to the fuel purchaser, which would result in a larger increase in truck VMT and a larger rebound effect.

If all of these scenarios occur in the marketplace, the net effect will depend on the extent and relative magnitude of their individual effects, which are also likely to vary across truck classes (for instance, split incentives may be a much larger problem for combination tractors than they are for HD pickups and vans). NHTSA intends to study this issue further as more information becomes available.

E. Other factors and conditions that could have an impact on a program to improve MHDV fuel efficiency

As discussed above, the final thing that Congress directed NHTSA to consider in developing a fuel efficiency improvement program for MD/HD vehicles was

> …such other factors and conditions that could have an impact on a program to improve commercial medium- and heavy-duty on-highway vehicle and work truck efficiency.

49 U.S.C. § 32902(k)(1)(D). There are, of course, a nearly infinite number of "factors and conditions that *could* have an impact on a program to improve" MHDV fuel efficiency, if Congress' words are taken too literally – NHTSA would never get around to regulating if we considered in much detail every single factor and condition that could impact a fuel efficiency improvement program. For purposes of this study, and given the context of the proposed HD National Program, NHTSA believes that it is reasonable to interpret Congress' direction to refer to the potential for "unintended consequences," as the NAS committee described the possible negative outcomes of creating a regulatory program that NHTSA should consider and try to mitigate as it develops the program. We seek comment on whether there are additional factors and conditions not covered in either this study or in the NPRM accompanying this study that NHTSA and EPA should consider and attempt to evaluate for the final rule.

This study will consider these unintended consequences in turn below.

1. What other factors and conditions did NAS identify as ones that could affect a MHDV fuel efficiency improvement program?

NAS mentioned multiple "indirect effects and externalities" or "unintended consequences" that should be addressed in a program to improve MHDV fuel efficiency. This section briefly summarized those issues, listed below.

- Fleet turnover effects
- Ton-miles traveled and the rebound effect[408]
- Vehicle class shifting by customers
- Environmental co-benefits and costs
- Congestion
- Safety impacts
- Incremental weight effects
- Manufacturability and product development

<u>Fleet turnover effects</u>:

The NAS committee stated that the implementation of regulations that increase the capital costs of new vehicles could have an effect on consumer purchase decisions, especially when access to capital is limited.[409] The committee noted that if that occurred, consumers may choose to maintain their existing vehicle in order to extend its life rather than purchasing a new (more expensive) vehicle.[410] If the existing vehicles are less efficient than the new ones, then, the overall effect of the regulation in terms of fuel

[408] The rebound effect is discussed above in terms of total vehicle energy consumption and operating costs, and is therefore not discussed again in this section, although NAS raised it in this context.
[409] NAS Report, at 150.
[410] Id.

savings may be dampened or even counterproductive.[411] The committee emphasized that this issue needed further analysis.[412]

Besides the decision to delay new purchases, the committee also noted that consumers may decide to accelerate their purchase schedule in order to obtain a new vehicle before the adoption of a new standard.[413] This would help them to defer having to deal with the incremental cost of the standard until their next purchase cycle.[414] The committee also indicated that buyers may "pre-buy" new vehicles due to concern about the reliability of unproven technology, effectively waiting to see how the new technology performs without incurring risk themselves.[415]

These "pre-buy" decisions result in "low-buy" of vehicles following the introduction of new, more costly vehicles meeting the new standards.[416] The committee stated that such impacts have been observed recently in association with the adoption of EPA's 2004 and 2007 HD emissions standards and the associated price increases for vehicles that had to meet them, noting a "general industry consensus" that the sizable peak in sales in 2006 was largely attributable to pre-buy behavior in advance of more stringent and costly NO_X and PM standards being introduced in the following years.[417] The committee discussed a 2008 economic analysis of pre-buy and low-buy impacts for Class 8 trucks between 2005 and 2008 as indicating that the aggregate impact was estimated to result in a net increase in national annual NO_X emissions in 2010 of more than 50,000 tons, or about 1 percent of expected NO_X emissions from all on-road sources.[418] The committee stated that even though under potential fuel efficiency standards, some or all of the incremental vehicle cost may eventually be recouped through future fuel savings, buyer responses to the cost increases associated with previous NO_X and OM standards could provide a rough sense of the possible pre-buy and low-buy impacts associated with future fuel efficiency regulations, given the payback periods expected by most HD fleet operators.[419]

Vehicle class shifting by consumers:

The committee stated that since manufacturers need to balance issues of performance, cost, and fuel efficiency, when regulation incentivizes a certain class of vehicles to meet a fuel efficiency standard at the expense of performance, a potential buyer may choose to purchase a larger class vehicle to offset the performance losses.[420] Also, similar to the pre-buy and low-buy effects discussed above, the committee noted that truck purchasers may seek to avoid increased capital costs for new trucks under the

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[411] Id.
[412] Id
[413] Id.
[414] Id.
[415] Id.
[416] Id.
[417] Id.
[418] Id.
[419] Id. at 151.
[420] Id. at 152.

new regulations by switching the type of vehicle they buy.[421] Both of these behaviors would lead to less efficient vehicles on the road – the opposite effect of what a fuel efficiency improvement program is designed to achieve.[422] However, the committee found little or no literature that evaluates class shifting between trucks.[423] The committee indicated that this issue needed further research.

Environmental Co-Benefits and Costs:

The NAS committee noted that improvements in fuel efficiencies could improve other emissions (namely NO_X and PM), although it also recognized that there are a few cases where improving engine efficiency could increase other emissions.[424] However, the committee also stressed that trucks will still need to comply with EPA's 2007-2010 criteria pollutant emissions standards regardless of any fuel efficiency improvement regulations.[425]

Congestion:

The NAS committee noted that the rebound effect, discussed above, may result in increased VMT, which could in turn increase congestion.[426] In addition, if the engine power is degraded as a result of the new fuel economy standards, trucks may need to travel slower, especially on inclines, which could negatively impact congestion levels.[427] The committee considered two ways in which congestion impacts could be calculated, and cited one source as estimating the marginal congestion cost (the cost, measured in lost travel time, that a single additional vehicle imposes on the rest of the traffic already on the roadway) of combination trucks to be $0.168/mile in urban areas and $0.037/mile in rural areas.[428] The committee stated that generally, as congestion increases, the marginal cost increases.[429]

Safety:

The committee identified five potential safety impacts. First, new technologies may have new safety considerations – for example, hybridization involves new high-voltage electrical equipment and mechanics and first responders may need to new training on dealing with that equipment.[430] Second, the rebound effect may increase VMT, and thus have safety impacts due to additional vehicle operation.[431] Third, some technologies that improve fuel efficiency may increase safety (particularly for other road

[421] Id.
[422] Id.
[423] Id.
[424] Id. at 152.
[425] Id.
[426] Id. at 152-153.
[427] Id. at 152.
[428] Id. at 153.
[429] Id.
[430] Id.
[431] Id.

users), such as if they result in slower speeds.[432] Fourth, some new technologies may decrease safety – for example, if the technology negatively affects acceleration.[433] Lastly, if the new technology increases payload capacity, fewer trucks may be on the road, resulting in safer driving conditions.[434] The committee offered a preliminary estimate of costs from additional crashes based on a 2006 study commissioned by FMCSA, with injury costs defined as representing the present value (at a 4 percent discount rate) of all costs over the victims' expected life span that result from a crash.[435] The committee estimated that for crashes involving a truck tractor with one trailer, costs of crashes with injuries in 2006 would be $200,000, while costs for fatal crashes would be $3,800,000.[436]

Effects of incremental changes in weight:

Certain fuel savings technologies may increase the gross weight of the vehicle, which can affect vehicle operating cost.[437] NAS identified several effects of such a potential weight increase, including (1) additional weight partially offsetting the fuel efficiency gains due to the standards; (2) some vehicles may be pushed into higher weight classes, making them subject to additional regulations; (3) some vehicles may bump against the 80,000-lb. legal gross weight limit for most major U.S. roads, which would result in reduced cargo capacity and in turn lead to higher VMT as more vehicles are needed to transport the same amount of cargo; and (4) additional wear on roads and bridges may occur due to the heavier vehicles.[438] The committee noted that fuel-saving technologies that add weight include engine efficiency improvements such as turbocompound systems and waste heat recovery systems; hybrid power systems; and aerodynamic fairings (up to 500 lbs).[439]

2. What other factors and conditions does NHTSA think could impact a program to improve MHDV fuel efficiency?

Tracking the discussion above of NAS' consideration of unintended consequences, this section discusses each of the factors and conditions in turn.

Fleet turnover effects:

A regulation that increases the cost to purchase and/or operate trucks could impact whether a consumer decides to purchase a new truck and the timing of that purchase. The term "pre-buy" refers to the idea that truck purchases may occur earlier than otherwise planned to avoid the additional costs associated with a new regulatory

[432] Id.
[433] Id.
[434] Id. at 154.
[435] Id.
[436] Id.
[437] Id.
[438] Id.
[439] Id. at 155.

requirement. Slower fleet turnover, or "low-buys," may occur when owners opt to keep their existing truck rather than purchase a new truck due to the incremental cost of the regulation.

As discussed above, the NAS committee discussed the topics associated with HD truck fleet turnover. The committee noted that there is some empirical evidence of pre-buy behavior in response to the 2004 and 2007 heavy-duty engine emission standards, with larger impacts occurring in response to higher costs.[440] However, those regulations increased upfront costs to firms without any offsetting future cost savings from reduced fuel purchases. In summary, the committee stated that

> …during periods of stable or growing demand in the freight sector, pre-buy behavior may have significant impact on purchase patterns, especially for larger fleets with better access to capital and financing. Under these same conditions, smaller operators may simply elect to keep their current equipment on the road longer, all the more likely given continued improvements in diesel engine durability over time. On the other hand, to the extent that fuel economy improvements can offset incremental purchase costs, these impacts will be lessened. Nevertheless, when it comes to efficiency investments, most heavy duty fleet operators require relatively quick payback periods, on the order of two to three years.[441]

The standards proposed in the NPRM are projected to return fuel savings to the truck owners that offset the cost of the regulation within a few years for vocational vehicles and Class 7 and 8 tractors, the categories where the potential for pre-buy and delayed fleet turnover are concerns. In the case of vocational vehicles, the agencies believe that the added cost is small enough that it is unlikely to have a substantial effect on purchasing behavior. In the case of Class 7 and 8 trucks, the effects of the regulation on purchasing behavior will depend on the nature of the market failures and the extent to which firms consider the projected future fuel savings in their purchasing decisions.

If trucking firms account for the rapid payback, the agencies believe that they are unlikely to accelerate or delay their purchase plans strategically at additional cost in capital to avoid a regulation that will lower their overall operating costs. As discussed in Section VIII.A of the NPRM accompanying this study, this scenario may occur if this proposed rule reduces uncertainty about fuel-saving technologies. More reliable information about ways to reduce fuel consumption allows truck purchasers to evaluate better the benefits and costs of additional fuel savings, primarily in the original vehicle market, but possibly in the resale market as well.

Other market failures may leave open the possibility of some pre-buy or delayed purchasing behavior. Firms may not consider the full value of the future fuel savings for several reasons. For instance, truck purchasers may not want to invest in fuel economy because of uncertainty about fuel prices. Another explanation is that the resale market

[440] Id. at 150.
[441] Id. at 151.

may not fully recognize the value of fuel savings, due to lack of trust of new technologies or changes in the uses of the vehicles. Lack of coordination (also called split incentives—see NPRM Section VIII.A) between truck purchasers (who emphasize the up-front costs of the trucks) and truck operators, who would like the fuel savings, can also lead to pre-buy or delayed purchasing behavior. If these market failures prevent firms from fully internalizing fuel savings when deciding on vehicle purchases, then pre-buy and delayed purchase could occur and could result in a slight decrease in the fuel savings and GHG benefits of the regulation.

Thus, whether pre-buy or delayed purchase is likely to play a significant role in the truck market depends on the specific behaviors of purchasers in that market. Without additional information about which scenario is more likely to be prevalent, NHTSA and EPA are not projecting a change in fleet turnover characteristics due to the proposed regulation.

Class Switching: NHTSA agrees with the NAS committee that there is little or no literature that evaluates class shifting between trucks.[442] To begin to address this issue for purposes of the NPRM accompanying this study, NHTSA and EPA qualitatively evaluated the proposed rule in light of potential class shifting. The agencies looked at four potential cases of shifting -- from light-duty pickup trucks to heavy-duty pickup trucks, from sleeper cabs to day cabs, from combination tractors to vocational vehicles, and within vocational vehicles.

Pickup trucks: Light-duty pickup trucks, those with a GVWR of less than 8,500 pounds, are currently regulated under the existing CAFE program and will meet GHG emissions standards beginning in 2012. The increased stringency of the MYs 2012-2016 CAFE and GHG light-duty rule has led some to speculate that vehicle consumers may choose to purchase heavy-duty pickup trucks that are currently unregulated if increases in price due to the light-duty regulation are high relative to the price of the larger heavy-duty pickup trucks. Since fuel consumption and GHG emissions rise significantly with vehicle mass, a shift from light-duty trucks to heavy-duty trucks would likely lead to higher fuel consumption and GHG emissions, an untended consequence of the regulations.

Given the significant price premium of a heavy-duty truck (often $5,000 to $10,000 more than a light-duty pickup), the agencies tentatively concluded that such a class shift would be unlikely even absent the proposed standards in the NPRM accompanying this study. By beginning to regulate the fuel efficiency and GHG emissions of heavy-duty pickups, the agencies believe that any incentive for such a class shift is significantly diminished. The proposed regulations for HD pickup trucks, and similarly for vans, are based on many similar technologies and thus reflect a similar expected increase in cost relative to that expected as a result of the light-duty fuel economy and GHG standards. For this reason, the agencies expect that the combination of the two regulations would provide little incentive for a shift by consumers from purchasing light-duty pickups to purchasing HD pickups.

[442] Id. at 152.

On the other hand, if the increase in vehicle price for HD pickups and vans due to the proposed regulations is relatively larger than the increase in price in light-duty pickups due to the MYs 2012-2016 CAFE and GHG regulations, we could expect some degree of class shifting by purchasers of HD pickups and vans to light-duty pickups and vans. To the extent that our proposed regulation of heavy-duty pickups and vans could conceivably encourage a class shift towards lighter pickups, this unintended consequence would be expected to lead to lower fuel consumption and GHG emissions, as the smaller light-duty pickups are significantly more efficient than heavy-duty pickup trucks.

Sleeper/day cabs: The projected cost increases for the proposed standards in the NPRM accompanying this study differ significantly between Class 8 day cabs and Class 8 sleeper cabs, reflecting our expectation that compliance with the proposed standards will cause truck consumers to specify sleeper cabs equipped with auxiliary power units while day cab consumers will not. Since Class 8 day cab and sleeper cab trucks perform essentially the same function when hauling a trailer, this raises the possibility that the higher cost for an APU equipped sleeper cab could lead to a shift from sleeper cab to day cab trucks.

NHTSA and EPA do not believe that such an unintended consequence will occur for the following reasons. The addition of a sleeper berth to a tractor cab is not a consumer-selectable attribute in quite the same way as other vehicle features. The sleeper cab provides a utility that long-distance trucking fleets need to conduct their operations -- an on-board sleeping berth that lets a driver comply with federally-mandated rest periods, as required for on-road safety by the Federal Motor Carrier Safety Administration's hours-of-service regulations. The cost of sleeper trucks is already higher than the cost of day cabs, yet the fleets that need this utility purchase them.[443] A day cab simply cannot provide this utility. The need for this utility would not be changed even if the marginal costs to reduce greenhouse gas emissions and fuel consumption from sleeper cabs exceed the marginal costs to reduce emissions and fuel consumption from day cabs. We note that a trucking fleet could decide to put its drivers in hotels in lieu of using sleeper berths, and thus be able to switch to day cabs, but we believe this is unlikely to occur with much frequency, since the added cost for the hotel stays would far outweigh differences in the marginal cost between day and sleeper cabs. Even if some fleets do opt to rent hotel rooms and switch to day cabs, they would be highly unlikely to purchase a day cab that was aerodynamically worse than the sleeper cab they replaced, since the need for features optimized for long-distance hauling would not have changed. Thus, as a practical matter, the impact of any class shifting from sleeper cabs to day cabs would likely be minimal in terms of emissions and fuel consumption reductions.

Further, while our projected costs in the NPRM accompanying this study assume the purchase of an APU for compliance, the regulatory structure would alternatively allow compliance using a near zero cost software utility that eliminates tractor idling after

[443] A baseline tractor price of a new day cab is $89,500 versus $113,000 for a new sleeper cab based on information gathered by ICF in the "Investigation of Costs for Strategies to Reduce Greenhouse Gas Emissions for Heavy-Duty On-Road Vehicles," July 2010. Page 3.

5 minutes. This alternative compliance approach is provided to reflect the fact that some sleeper cabs are used in team driving situations, where one driver sleeps while the other drives, such that an APU is unnecessary since the tractor is continually being driven when occupied. When it is parked, it will automatically eliminate any additional idling through the shutdown software. Using this compliance approach, the cost difference between a Class 8 sleeper cab and day cab due to our proposed regulations is small. Moreover, if trucking companies choose this option, then costs based on purchase of APUs may overestimate the costs of this rule to this sector. We note, of course, that this alternative compliance option likely only makes sense for fleets that employ team drivers; single drivers of sleeper cabs would need an APU, or would need to rent a hotel room.

Combination tractors/vocational vehicles: Class shifting from combination tractors to vocational vehicles may occur if a customer deems the additional marginal cost of tractors due to the regulation to be greater than the utility provided by the tractor. The agencies initially considered this issue when deciding whether to include Class 7 tractors with the Class 8 tractors or regulate them as vocational vehicles. The agencies' evaluation of the combined vehicle weight rating of the Class 7 shows that if these vehicles were treated significantly differently from the Class 8 tractors, then they could be easily substituted for Class 8 tractors. Therefore, the agencies are proposing to include both classes in the tractor category. The agencies believe that a shift from tractors to vocational vehicles would be limited because of the ability of tractors to pick up and drop off trailers at locations that cannot be done by vocational vehicles.

The agencies do not envision that the proposed regulatory program will cause class shifting within the vocational class. The marginal cost difference due to the regulation of vocational vehicles is minimal. The cost of low rolling resistance tires on a per tire basis is the same for all vocational vehicles, so the only difference in marginal cost of the vehicles is due to the number of axles. The agencies believe that the utility gained from the additional load carrying capability of the additional axle will outweigh the additional cost for heavier vehicles.[444]

In conclusion, NHTSA and EPA believe that the proposed regulatory structure for HD trucks does not significantly change the current competitive and market factors that determine purchaser preferences among truck types. Furthermore, even if a small amount of shifting does occur, any resulting GHG impacts are likely to be negligible because any vehicle class that sees an uptick in sales is also being regulated for fuel economy. As a result, the agencies did not include an impact of class shifting on the vehicle populations used to assess the benefits of the proposal, but are seeking comments on this issue to inform the benefits assessment of the final rule.

Environmental co-benefits and costs:

NHTSA also agrees that it is important to quantify the other environmental impacts (other than the direct effects on carbon emissions related to improved fuel

[444] The proposed rule projects the difference in costs between the HD and MD vocational truck technologies is approximately $30.

efficiency) associated with the proposed regulations, and has done so in the NPRM accompanying this study. In addition, NHTSA and EPA discuss the associated impacts on health that result from these emissions. EPA customarily quantifies and monetizes the health and environmental impacts related to both PM and ozone in its regulatory impact analyses (RIAs), when possible, but was unable to do so in time for the NPRM. Instead, for the NPRM, a characterization of the health and environmental impacts that will be quantified and monetized for the final rule are included.

Chapter 8.3 in the DRIA that accompanies the NPRM lists the co-pollutant health effect exposure-response functions that EPA will use to quantify the co-pollutant incidence impacts associated with the final heavy-duty vehicles standard. These include PM- and ozone-related premature mortality, chronic bronchitis, nonfatal heart attacks, hospital admissions (respiratory and cardiovascular), emergency room visits, acute bronchitis, minor restricted activity days, and days of work and school lost. The health impacts will also be monetized using EPA's value of statistical life (VSL) and EPA's willingness-to-pay estimates from the valuation literature.[445] We note, however, that there are some impacts that EPA will not be able to quantify or monetize.

Congestion, Safety, and Noise:

To the extent that the proposed increases in fuel efficiency result in an increase in VMT from the rebound effect (discussed above), we agree with the NAS committee that there will also be congestion and safety impacts. Congestion could also increase if vehicle class shifting causes operators to replace larger trucks with multiple smaller trucks, which have less upfront capital. On the other hand, if manufacturers are able to increase payload as a result of new standards, congestion could decrease. Increased VMT would also affect highway noise levels.

In the NPRM accompanying this study, NHTSA and EPA rely on the 1997 FHWA *Federal Highway Cost Allocation Study* for quantifying and monetizing these costs.[446] The FHWA estimates are intended to measure the increases in costs from added congestion, property damages and injuries in traffic accidents, and noise levels caused by automobiles and light trucks that are borne by persons other than their drivers (or "marginal" external costs). EPA and NHTSA also employed estimates from this source in the analysis accompanying the recent light-duty vehicle CAFE and GHG final rule. The agencies continue to find them appropriate for this HD analysis after reviewing the procedures used by FHWA to develop them and considering other available estimates of these values. FHWA's congestion estimates for trucks already consider that trucks account for a lower percent of peak period traffic on congested freeways because they try to avoid peak periods when possible. The FHWA congestion costs are a weighted average based on the estimated percent of peak and off-peak freeway travel for each of the classes of trucks. FHWA focused congestion costs on freeways because non-freeway effects are less serious because of lower traffic volumes and opportunities to re-route

[445] For purposes of the final rule analysis, EPA and NHTSA will consider ways of monetizing impacts that reflect both EPA's and DOT's respective VSLs.
[446] *See* www.fhwa.dot.gov/policy/hcas/final/index.htm (last accessed Sept. 20, 2010).

around the congestion. The agencies, however, applied the congestion cost to the overall VMT increase, though the fraction of VMT on each road type used in MOVES ranged from 27 to 29 percent of the vehicle miles on freeways for vocational vehicles and 53 percent for combination trucks. The results of this analysis potentially overestimate the costs and provide a conservative estimate, so in the NPRM accompanying this study, the agencies welcome comments on whether the cost calculations should be done differently in the final rule.

Instead of using the estimates cited by the NAS committee, in the NPRM accompanying this study the agencies are proposing to use FHWA's "Middle" estimates for the marginal congestion, accident, and noise costs caused by increased travel from trucks. This approach is consistent with the current methodology used in the recent light-duty vehicle CAFE and GHG rulemaking analysis. These costs are multiplied by the annual increases in vehicle miles travelled from the positive rebound effect to yield the estimated increases in congestion, accident, and noise externality costs during each future year. The values the agencies used in the calculation of the congestion, noise, and accident costs are included in Table III.E.1 below.

Table III.E.1: Noise, Accident, and Congestion Costs per Mile (2008$)

External Costs	Pickup truck and vans ($/VMT)	Vocational vehicles ($/VMT)	Combination trucks ($/VMT)
Congestion	$ 0.049	$ 0.110	$ 0.107
Accidents	$ 0.026	$ 0.019	$ 0.022
Noise	$ 0.001	$ 0.009	$ 0.020

In aggregate, the external costs due to noise, accidents, and congestion from the additional truck driving are presented in Table III.E.2 below.

Table III.E.2: Accident, Noise, and Congestion Costs (Millions, 2008$)

Year	Class 2b&3	Vocational	Combination	EXTERNAL COSTS
2012	$0	$0	$0	$0
2013	$0	$0	$0	$0
2014	$8	$10	$18	$36
2015	$16	$19	$35	$70
2016	$23	$30	$52	$104
2017	$30	$39	$68	$137
2018	$37	$48	$83	$168
2020	$50	$64	$111	$225
2030	$89	$122	$193	$404
2040	$112	$182	$233	$527
2050	$133	$245	$271	$648
NPV, 3%	$1,606	$2,407	$3,439	$7,452
NPV, 7%	$746	$1,070	$1,614	$3,429

Effects of incremental changes in weight:

NHTSA agrees with the NAS committee that certain fuel savings technologies may increase the gross weight of the vehicle, which can affect vehicle operating cost, but thinks that generally manufacturers will have sufficient incentive to keep the weight of MD/HD vehicles down in order to maximize utility that these impacts should be fairly minimal.

Besides the potential weight increases identified by the NAS committee as possible, in the NPRM and DRIA accompanying this study, NHTSA also considered the effect of safety standards and voluntary safety improvements on vehicle weight, and discussed briefly some of NHTSA's work on the effects of vehicle weight on safety in the light-duty context.

The Effect of Safety Standards and Voluntary Safety Improvements on Vehicle Weight

Safety regulations developed by NHTSA in previous regulations may make compliance with the proposed HD fuel efficiency standards more difficult or may reduce the projected benefits of the program. The primary way that safety regulations can impact fuel efficiency and GHG emissions is through increased vehicle weight, which reduces the fuel efficiency of the vehicle.

Using MY 2010 as a baseline, this section discusses the effects of other government regulations on MYs 2014-2016 MHDV fuel efficiency. At this time, no known additional safety standards will affect new models in MY 2017 or 2018. The agency's estimates are based on cost and weight tear-down studies of a few vehicles and do not cover all the variations in the manufacturers' fleets. Our estimates of increases in weight resulting from safety improvements are shown in subsequent tables.

We have broken down our analysis of the impact of safety standards that might affect the MYs 2014-2016 fleets into three parts: (1) those NHTSA final rules with known effective dates, (2) proposed rules or soon to be proposed rules by NHTSA with or without final effective dates, and (3) currently voluntary safety improvements planned by the manufacturers.

Weight impacts of required safety standards:

NHTSA has undertaken several rulemakings in which several standards would become effective for MD/HD vehicles between MY 2014 and MY 2016. We will examine the potential impact on MHDV weights for MYs 2014-2016 using MY 2010 as a baseline.

- FMVSS No. 119, Heavy-Truck Tires Endurance and High-Speed Tests
- FMVSS No. 121, Air Brake Systems Stopping Distance

- FMVSS No. 214, Motor Coach Lap/Shoulder Belts
- MD/HD Vehicle Electronic Stability Control Systems

FMVSS No. 119, Heavy-Truck Tires Endurance and High-Speed Tests:

The data in the large-truck crash causation study and the agency's test results indicate that J and L load range tires are more likely to fail the proposed requirements among the targeted F, G, H, J and L load range tires.[447] As such the J and L load range tires specifically need to be addressed to meet the proposed requirements since the other load range tires are likely to pass the requirements. Rubber material improvements such as improving rubber compounds would be a countermeasure that reduces heat retention and improve the durability of the tires. Using high-tensile-strength steel chords in tire bead, carcass and belt would enable a weight reduction in construction with no strength penalties. The rubber material improvements and using high-tensile-strength steel would not add any additional weight to the current production heavy truck tires. Thus there may not be an incremental weight per vehicle for the period of MYs 2014-2016 compared to the MY 2010 baseline. This proposal could become a final rule with an effective date of MY 2016.

FMVSS No. 121, Airbrake Systems Stopping Distance:

The most recent major final rule was published on July 27, 2009, and became effective on November 24, 2009 (MY 2009), with different compliance dates. The final rule requires the vast majority of new heavy-truck tractors (approximately 99 percent of the fleet) to achieve a 30-percent reduction in stopping distance compared to currently required levels. Three-axle tractors with a GVWR of 59,600 pounds or less must meet the reduced stopping distance requirements by August 1, 2011 (MY 2011). Two-axle tractors and tractors with a GVWR above 59,600 pounds must meet the reduced stopping distance requirements by August 1, 2013 (MY 2013). There are several brake systems that can meet the requirements in the final rule. Those systems include installation of larger S-cam drum brakes or disc brake systems at all positions, or hybrid disc and larger rear S-cam drum brake systems.

According to the data provided by a manufacturer (Bendix), the heaviest drum brakes weigh more than the lightest disc brakes while the heaviest disc brakes weigh more than the lightest drum brakes. For a three-axle tractor equipped with all disc brakes, the total weight could increase by 212 pounds or could decrease by 134 pounds compared to an all-drum-braked tractor depending on which disc or drum brakes are used for comparison. The improved brakes may add a small amount of weight to the affected vehicle for MYs 2014-2016 resulting in a slight increase in fuel consumption.

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[447] "Preliminary Regulatory Impact Analysis, FMVSS No. 119, New Pneumatic Tires for Motor Vehicles with a GVWR of More Than 4,536 kg (10,000 pounds), June 2010.

FMVSS No. 208, Motor coach lap/shoulder belts:

Based on preliminary results from the agency's cost/weight teardown studies of motor coach seats, it is estimated that the weight added by 3-point lap/shoulder belts ranges from 5.96 to 9.95 pounds per 2-person seat.[448] This is the weight only of the seat belt assembly itself and does not include changing the design of the seat, reinforcing the floor, walls or other areas of the motor coach. Few current production motor coaches have been installed with lap/shoulder belts on their seats, and the number could be negligible. Assuming a 54-passenger motor coach, the added weight for the 3-point lap/shoulder belt assembly is in the range of 161 to 269 pounds (27 * [5.96 to 9.95]) per vehicle. This proposal could become a final rule with an effective date of MY 2016.

Electronic stability control (ESC) systems for MD/HD vehicles:

ESC is not currently required in MD/HD vehicles but could be proposed to be required in the vehicles by NHTSA. FMVSS No. 105, Hydraulic and electric brake systems, requires multipurpose passenger vehicles, trucks and buses with a GVWR greater than 4,536 kg (10,000 pounds) to be equipped with an antilock brake system. All MD/HD vehicles have a GVWR of more than 10,000 pounds, and these vehicles are required to be installed with an ABS by the same standard.

ESC incorporates yaw rate control into the ABS, and yaw is a rotation around the vertical axis. ESC systems use several sensors in addition to the sensors used in the ABS, which is required in MD/HD vehicles. Those additional sensors could include steering wheel angle sensor, yaw rate sensor, lateral acceleration sensor and wheel speed sensor. According to the data provided by Meritor WABCO, the weight of the ESC for the model 4S4M tractor is estimated to be around 55.494 pounds, and the weight of the ABS only is estimated to be 45.54 pounds. Then the added weight for the ESC for the vehicle is estimated to be 9.954 (55.494 – 45.54) pounds.

Summary – Overview of Anticipated Weight Increases

Table III.E.3 below summarizes estimates made by the agency regarding the weight added by the above discussed standards or likely rulemakings. The agency estimates that weight additions required by final rules and likely NHTSA regulations effective in MY 2016 compared to the MY 2010 fleet will increase motorcoach vehicle weight by 171-279 pounds and will increase other heavy duty truck weights by a minor 10 pounds.

[448] Cost and Weight Analysis of Two Motorcoach Seating Systems: One With and One Without Three-Point Lap/Shoulder Belt Restraints, Ludkes and Associates, July 2010.

Table III.E.3: Weight Additions Due to Final Rules or Likely NHTSA Regulations Comparing MY 2016 to the MY 2010 Baseline Fleet

Standard Number	Added Weight in Pounds MD/HD Vehicle	Added Weight in Kilograms MD/HD Vehicle
119	0	0
121	0 (?)	0 (?)
208 Motorcoaches only	161-269	73-122
MD/HD vehicle electronic stability control systems	10	4.5
Total motorcoaches	171- 279	77.5-126.5
Total all other MD/HD vehicles	10	4.5

Effects of Vehicle Mass Reduction on Safety:

NHTSA and EPA have been considering the effect of vehicle weight on vehicle safety for the past several years in the context of our joint rulemaking for light-duty vehicle CAFE and GHG standards, consistent with NHTSA's long-standing consideration of safety effects in setting CAFE standards. Combining all modes of impact, the latest analysis by NHTSA for the MYs 2012-2016 final rule found that reducing the weight of the heavier light trucks (LT > 3,870) had a positive overall effect on safety, reducing societal fatalities.[449]

In the context of the current rulemaking for MHDV fuel consumption and GHG standards, one would expect that reducing the weight of medium-duty trucks similarly would, if anything, have a positive impact on safety. However, given the large difference in weight between light-duty vehicles and medium-duty trucks, and even larger difference between light-duty vehicles and heavy-duty vehicles with loads, the agencies believe that the impact of weight reductions of medium- and heavy-duty trucks would not have a noticeable impact on safety for any of these classes of vehicles.

Nevertheless, the agencies recognize that it is important to conduct further study and research into the interaction of mass, size and safety to assist future rulemakings, and we expect that the collaborative interagency work currently on-going to address this issue for the light-duty vehicle context may also be able to inform our evaluation of safety effects for the final rule. In the NPRM accompanying this study, we seek comment regarding potential safety effects due to weight reduction in the HD vehicle context, with

[449] "Final Regulatory Impact Analysis, Corporate Average Fuel Economy for MY 2012 - MY 2016 Passenger Cars and Light Trucks", NHTSA, March 2010, (Docket No. NHTSA-2009-0059-0344.1).

particular emphasis on commenters providing supporting data and research for HD vehicle weight reduction.

IV. Conclusion

NHTSA undertook this study in response to the Energy Independence and Security Act of 2007, in which Congress required both the National Academy of Sciences and NHTSA to conduct studies to help inform NHTSA's development of a new regulatory system to improve the fuel efficiency of medium- and heavy-duty trucks. The context for NHTSA's study changed with the President's request in May 2010 that NHTSA and EPA immediately begin work on a new joint rulemaking to establish fuel efficiency and greenhouse gas emission standards for medium- and heavy-duty trucks with the aim of issuing a final rule by July 30, 2011, over a year ahead of the schedule implied in EISA. NHTSA and EPA determined that in order to allow sufficient time for public comment and for the agencies to respond sufficiently to those comments in the final rule, a Notice of Proposed Rulemaking should be released no later than October 2010. The agencies are able to meet the President's ambitious time table for regulation in part because of our relatively simplified approach, which is different than the more holistic and complicated approach envisioned by NAS, but which should contribute to significant improvements in fuel efficiency while minimizing the impact on the segments of the medium- and heavy-duty truck industry that are more complicated to regulate given their diversity.

This study, therefore, must be understood and considered as part of a unit along with the accompanying NPRM and Draft Regulatory Impact Analysis. While this document helps to explain NHTSA's decisions in the NPRM in the context of the tasks given to NHTSA by Congress in EISA, and to relate the NAS recommendations to the agency's decisions in a more detailed way than NHTSA and EPA were able to include in the accompanying NPRM, NHTSA emphasizes that it recognizes that much more study needs to be done given the lack of information regarding the impacts of fuel efficiency regulations on the MD/HD fleet. NHTSA intends to continue its study going forward, to ensure that subsequent phases of the HD National Program are well-informed, and to help ensure that the best information is available both to the government and to the public as the National Program continues.

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