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Review and Analysis of Potential Safety Impacts of and Regulatory Barriers to Fuel Efficiency Technologies and Alternative Fuels In Medium- and Heavy-Duty Vehicles

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16. Abstract

This report summarizes a safety analysis of medium- and heavy-duty vehicles (MD/HDVs) equipped with fuel efficiency (FE) technologies and/or using alternative fuels (natural gas-CNG and LNG, propane, biodiesel and power train electrification). The study included a comprehensive literature review, complemented with inputs from subject matter experts (SMEs), and a scenario-based hazard analysis. Specific FE technologies examined include: Intelligent Transportation Systems (ITS) and telematics, speed limiters, idle reduction devices, tire technologies (single-wide tires, tire pressure monitoring systems-TPMS and Automated Tire Inflation Systems-ATIS), aerodynamic components, long combination vehicles (LCVs) and lightweighting materials. Federal and State safety regulations, and voluntary technical standards affecting MD/HDV fleet adoption of FE technologies and alternative fuels were discussed, and potential regulatory barriers identified. The findings suggest that the potential safety hazards identified can be prevented or mitigated by complying with safety regulations and voluntary standards and industry best practices. The study did not identify any major regulatory barriers to rapid adoption of FE technologies and alternative fuels by the MD/HDV fleet.

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ACRONYMS AND SELECTED GLOSSARY

ABS	anti-lock brake system
AFDC	Alternative Fuels Data Center
AFV	alternative fueled vehicle
AHSS	advanced high strength steel
ANL	Argonne National Laboratory
ANSI	American National Standards Institute
APTA	American Public Transportation Association
APU	auxiliary power unit
ATIS	automatic tire inflation system
ATRI	American Transportation Research Institute
AVTA	advanced vehicle testing activity
BASIC	Behavior Analysis and Safety Improvement Categories; a relative ranking of carriers among their peers according to safety performance, as measured by the SMS
BCCS	Bus Crash Causation Study
BP	best practice
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CC	clean carrier; a carrier that is a member of the DOE National Clean Fleets Partnership
CF	conventional fleet
CDL	commercial driver license
CFRC	carbon fiber reinforced composite
CFRP	carbon fiber reinforced plastics
CMV	commercial motor vehicle
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CSA	Compliance, Safety, Accountability; an FMCSA initiative to improve truck and bus carriers' safety
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DOC	diesel oxidation catalysts
DOE	Department of Energy
DPF	diesel particulate filter
DTNA	Daimler Truck North America
EC	European Commission
ECM	electronic control module
EGR	exhaust gas recirculation
EIA	Energy Information Administration
EMT	Emergency Management Technician
EPA	Environmental Protection Agency
ESC	electronic stability control
ESS	energy storage system
EV	electric vehicle

FARS	Fatality Analysis Reporting System; a NHTSA database of fatal crashes
FE	fuel efficiency
FEI	fuel efficiency improvement
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMCSR	Federal Motor Carrier Safety Regulations
FMVSS	Federal Motor Vehicle Safety Standards
FRP	fiber reinforced plastics
GEG	gasoline-equivalent gallon (GEG); the amount of alternative fuel with equal the energy content of a gallon of gasoline
GBO	green bus operators; these have signed the APTA sustainability commitment
GES	General Estimates System, a NHTSA crash database
GGE	gasoline gallon equivalent (GGE); the amount of alternative fuel that contains the energy of one gallon of gasoline
GHG	greenhouse gases
GPS	Global Positioning System
GVWR	gross vehicle weight rating
H_2	hydrogen
HDV	heavy-duty vehicle
HEV	hybrid electric vehicle
HHV	hybrid hydraulic vehicle
ICE	internal combustion engine
IIHS	Insurance Institute for Highway Safety
ISTEA	Intermodal Surface Transportation Efficiency Act (1991)
ITS	Intelligent Transportation Systems
LBT	Long Beach Transit
LCV	longer combination vehicle
LDWS	lane departure warning system
L&I	licensing and insurance; a data set in MCMIS
LNG	liquefied natural gas
LPG	liquefied petroleum gas, propane, or autogas
lpm	liters per minute
LRR	low rolling resistance
LTCCS	Large Truck Crash Causation Study
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
MCMIS	Motor Carrier Management Information System, an FMCSA database
MD/HDV	medium- and heavy-duty vehicles
MDV	medium-duty vehicle
mph	miles per hour
MSDS	Material Safety Data Sheet
MTBF	mean time between failures
MTBRC	mean time between road calls
MY	model year(s)
NACFE	North American Council for Freight Efficiency
NFPA	National Fire Protection Association
NGV	natural gas vehicle

NHTSA	National Highway Traffic Safety Administration
NO_x	nitrogen oxides
NREL	National Renewable Energy Laboratory
NTEA	National Truck Equipment Association
OEM	original equipment manufacturer
O&M	operations and maintenance
OOIDA	Owner Operator Independent Driver Association
PCIV	plastics and composites intensive vehicles
PHMSA	Pipelines and Hazardous Materials Administration
PM	particulate matter
PRD	pressure relief device
psi	pounds per square inch
PU	power unit; trucks or buses, excluding trailers
RESS	Rechargeable Energy Storage System
ROI	return on investment
RSC	roll stability control
SAE	Society of Automotive Engineers
SBMTD	Santa Barbara Municipal Transit District
SCR	selective catalytic reduction
SME	subject matter expert
SMS	Safety Measurement System; a process for assigning BASIC scores to carriers under the CSA initiative
SOP	standard operating procedure
TARDEC	United States Army Tank Automotive Research, Development And Engineering Center
TPMS	tire pressure maintenance system
UMTRI	University of Michigan Transportation Research Institute
VMT	vehicle miles traveled
VRU	vulnerable road user
WMATA	Washington Metropolitan Area Transit Authority

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EXECUTIVE SUMMARY

The 2010 National Research Council report *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles* evaluated technology options for improving the fuel efficiency (FE) of Class 2-8 medium and heavy-duty vehicles and recommended that NHTSA perform a thorough safety analysis to identify and evaluate potential safety issues. In 2011, NHTSA and EPA issued joint rulemaking for fuel efficiency and Greenhouse Gas (GHG) emissions of model year (MY) 2014-2018 MD/HDVs.

This report summarizes research and analysis findings on potential safety issues associated with both the diverse alternative fuels (natural gas-CNG and LNG, propane, biodiesel, and power train electrification), and the specific FE technologies recently adopted by the MD/HDV fleets. These include Intelligent Transportation Systems (ITS) and telematics, speed limiters, idle reduction devices, tire technologies (single-wide tires, and tire pressure monitoring systems-TPMS and automated tire inflation systems-ATIS), aerodynamic components, vehicle light-weighting materials, and long combination vehicles (LCVs).

Chapter 1 provides an overview of the study rationale, background, and key objective, namely to identify the technical and operational/behavioral safety benefits and disbenefits of MD/HDVs equipped with FE technologies and using emerging alternative fuels. Recent MD/HDV national fleet crash safety statistical averages are also provided for context, although no information exists in crash reports relating to specific vehicle FE technologies and fuels. Chapters 2 and 3 are organized by clusters of functionally-related FE technologies (e.g., tire systems, ITS, light-weighting materials, and aerodynamic systems) and alternative fuels, which are described and their respective associated potential safety issues are discussed.

Chapter 2 summarizes the findings from a comprehensive review of available technical and trade literature and Internet sources regarding the benefits, potential safety hazards, and the applicable safety regulations and standards for deployed FE technologies and alternative fuels. Chapter 2 safety-relevant fuel-specific findings include:

- Both CNG- and LNG-powered vehicles present potential hazards, and call for well-known engineering and process controls to assure safe operability and crashworthiness. However, based on the reported incident rates of NGVs and the experiences of adopting fleets, it appears that NGVs can be operated at least as safely as diesel MD/HDVs. Using natural gas instead of diesel fuel helps fleets comply with the MD/HD greenhouse gas rules that require up to 20 percent emissions reduction by 2018.
- There are no safety contraindications to the large scale fleet adoption of CNG or LNG fueled heavy-duty trucks and buses, and there is ample experience with the safe operation of large public transit fleets. Voluntary industry standards and best practices suffice for safety assurance, though improved training of CMV operators and maintenance staff in natural gas safety of equipment and operating procedures is needed.
- Observing CNG and LNG fuel system and maintenance facility standards, coupled with sound design, manufacture and inspection of natural gas storage tanks will further reduce the potential for leaks, tank ruptures, fires, and explosions.

- Biodiesel blends used as drop-in fuels have presented some operational safety concerns dependent on blending fraction, such as material compatibility, bio-fouling sludge accumulation, or cold-weather gelling. However, best practices for biodiesel storage, and improved gaskets and seals that are biodiesel resistant, combined with regular maintenance and leak inspection schedule for the fuel lines and components enable the safe use of biodiesel in newer MD/HDVs.
- Propane (LPG, or autogas) presents well-known hazards including ignition (due to leaks or crash) that are preventable by using overfill prevention devices (OPDs), which supplement the automatic stop-fill system on the fueling station side, and pressure release devices (PRDs). Established best practices and safety codes (e.g., NFPA) have proven that propane fueled MD/HDVs can be as operationally safe as the conventionally-fueled counterparts.
- As the market penetration of hybrid and electric drivetrain accelerates, and as the capacity and reliability of lithium ion batteries used in Rechargeable Energy Storage Systems (RESS) improve, associated potential safety hazards (e.g., electrocution from stranded energy, thermal runaway leading to battery fire) have become well understood, preventable and manageable. Existing and emerging industry technical and safety voluntary standards, applicable NHTSA regulations and guidance, and the growing experience with the operation of hybrid and electric MD/HDVs will enable the safe operation and large-scale adoption of safer and more efficient power-train electrification technologies.

The safety findings from literature review pertaining to the specific FE technologies implemented to date in the MD/HDV fleet include:

- Telematics—integrating on-board sensors, video, and audio alerts for MD/HDV drivers—offer potential improvements in both driver safety performance and fuel efficiency. Both camera and non-camera based telematics setups are currently integrated with available crash avoidance systems (such as ESC, RSC, LDWS, etc.) and appear to be well accepted by MD/HDV fleet drivers.
- Both experience abroad and the cited U.S. studies of trucks equipped with active speed limiters indicated a safety benefit, as measured by up to 50 percent reduced crash rates, in addition to fuel savings and other benefits, with good CMV driver acceptance. Any negative aspects were small and avoidable if all the speed limitation devices were set to the same speed, so there would be less need for overtaking at highway speeds.
- No literature reports of adverse safety impacts were found regarding implementation of on-board idle-reduction technologies in MD/HDVs (such as automatic start-stop, direct-fired heaters, and APUs).
- There was no clear consensus from the literature regarding the relative crash rates and highway safety impacts of LCVs, due to lack of sufficient data and controls and inconsistent study methodologies. Recent safety evaluations of LCVs and ongoing MAP-21 mandated studies will clarify and quantify this issue.
- Tire technologies for FE (including ATIS, TPMS, LRR and single-wide tires) literature raised potential safety concerns regarding lower stability or loss of control, e.g., when tire pressure is uneven or a single wide tire blows out on the highway. However, systems

such as automated tire monitoring systems and stability enhancing electronic systems (ABS, ESC, RSC) may compensate and mitigate any adverse safety impacts.

- Aerodynamic technologies that offer significant fuel savings have raised potential concerns about vehicle damage or injury in case of detached fairings or skirts, although there were no documented incidents of this type in the literature.
- Some light weighting materials may pose some fire safety and crashworthiness hazards, depending on their performance in structural or other vehicle subsystem applications (chassis, power-train, crash box or safety cage). Some composites (fiberglass, plastics, CFRC, foams) may become brittle on impact or due to weathering from UV exposure or extreme cold. Industry has developed advanced, high performance lightweight material options tailored to their automotive applications, e.g., thermoplastics resistant to UV and weathering. No examples of such lightweight material failures on MD/HDVs were identified in the literature.

Chapter 3 provides complementary inputs on the potential safety issues associated with FE technologies and alternative fuels obtained from Subject Matter Experts (SMEs). The broad cross-section of SMEs consulted had experience with the operation of “green” truck and bus fleets, were Federal program managers, or were industry developers of FE systems for MD/HDVs. Safety concerns raised by the SMEs can be prevented or mitigated by complying with applicable regulations and safety standards and best practices, and are being addressed by evolving technologies, such as electronic collision prevention devices. Although SMEs raised some safety concerns, their experience indicates that system- or fuel-specific hazards can be prevented or mitigated by observing applicable industry standards, and by training managers, operators and maintenance staff in safety best practices. Specific safety concerns raised by SMEs based on their experience included:

- Alternative fuels did not raise major safety concerns, but generally required better education and training of staff and operators. There was a concern expressed regarding high pressure (4,000 psi) CNG cylinders that could potentially explode in a crash scenario or if otherwise ruptured. However, aging CNG fuel tank safety can be assured by enforcing regulations such as FMVSS 304, and by periodic inspection and end-of-life disposal and replacement. A propane truck fleet manager found the fuel to be as safe as or safer than gasoline, and reported no safety issues with the company’s propane, nor with hybrid gasoline-electric trucks. OEMs of drivetrain hybridization and electrification systems, including advanced Lithium Ion batteries for RESS, indicated that they undergo multiple safety tests and are designed with fail-safes for various misuse and abuse scenarios. Integration of hybrid components downstream by bodybuilders in retrofits, as opposed to new vehicles was deemed a potential safety risk. Another potential safety concern raised was the uncertain battery lifetime due to variability of climate, and duty-cycles and aging. Without state-of-charge indicators, this could conceivably leave vehicles underpowered or stranded if the battery degrades and is not serviced or replaced in a timely manner.
- ITS and telematics raised no safety concerns; on the contrary, fleet managers stated that “efficient drivers are safer drivers.” Monitoring and recording of driver behavior, combined with coaching, appeared to reduce distracted and aggressive driving and provided significant FE and safety benefits.

- A wide-base single tire safety concern was the decrease in tire redundancy in case of a tire blowout at highway speeds. For LRRs, a concern was that they could negatively affect truck stopping distance and stability control.
- A speed-limiter safety concern was related to scenarios when such trucks pass other vehicles on the highway instead of staying in the right-hand lane behind other vehicles. By combining speed limiters with driver training programs, overall truck safety could actually improve, as shown by international practice.
- Aerodynamic systems safety performance to date was satisfactory, with no instances of on-road detaching. However, covering underside or other components with aerodynamic fairings can make them harder to inspect, such as worn lugs, CNG relief valve shrouds, wheel covers, and certain fairings. Drivers and inspectors need to be able to see through wheel covers and to be able to access lug nuts through them. These covers must also be durable to withstand frequent road abuse.
- For lightweighting materials, the safety concern raised was lower crashworthiness (debonding or brittle fracture on impact) and the potential for decreased survivability in vehicle fires depending on the specific material choice and its application.

The key finding from the literature review and SME interviews is that there are no major safety hazards preventing the adoption of FE technologies or the increased use of alternative fuels and vehicle electrification. In view of the scarcity of hard data currently available on actual highway crashes that can be directly or causally attributed to adoption of FE technologies and/or alternative fuels by MD/HDVs, and the limited experience with commercial truck and transit bus fleets operations equipped with these technologies, it was not possible to perform a quantitative, probabilistic risk assessment, or even a semi-quantitative preliminary hazard analysis (PHA). Thus, Chapter 4 employs a deterministic scenario-based hazard analysis of potential crash or other safety concerns identified from the literature review or raised by subject matter experts (SMEs) interviewed (e.g., interfaces with charging or refueling infrastructure). For each specific hazard scenario discussed, the recommended prevention or mitigation options, including compliance with applicable NHTSA or FMCSA regulations, and voluntary industry standards and best practices are identified, along with FE technology or fuel-specific operator training. SMEs safety concerns identified in Sec 3.3 were complemented with actual incidents, and developed into the hazard scenarios analyzed in Chapter 4.

The scenario-based deterministic hazard analysis reflected not only the literature findings and SME's safety concerns, but also real truck or bus mishaps that have occurred in the past. Key hazard analysis scenarios included: CNG-fueled truck and bus vehicle fires or explosions due to tank rupture, when pressurized fuel tanks were degraded due to aging or when PRDs failed; LNG truck crashes leading to fires, or LNG refueling-related mishaps; the flammability or brittle fracture issues related to lightweighting materials in crashes; reduced safety performance for either LRR or wide-base tires; highway pile-ups when LCVs attempt to pass at highways speeds; aerodynamic components detaching while the vehicle traveled on a busy highway or urban roadway; and fires resulting in overheated lithium ion batteries in electric or hybrid buses. These hypothetical worst case scenarios appear to be preventable or can be mitigated by observing safety regulations and voluntary standards, or with engineering and operational best practices.

Chapter 5 reviews and discusses the existing Federal and State regulatory framework for safely operating MD/HDVs equipped with FE technologies or powered by alternative fuels. The review identifies potential regulatory barriers to their large-scale deployment in the national fleet that could delay achievement of desired fuel consumption and environmental benefits, while ensuring equal or better safety performance.

Chapter 6 summarizes the major findings and recommendations of this preliminary safety analysis of fuel efficiency technologies and alternative fuels adopted by MD/HDVs. The scenario-based hazard analysis, based on the literature review and experts' inputs, indicates that MD/HDVs equipped with advanced FE technologies and/or using alternative fuels have manageable potentially adverse safety impacts. However, an in depth comparative statistical analysis of truck and bus crash databases over a longer time period (at least five years) is needed to understand quantitatively the safety implications of the rapid adoption of "green" technologies and fuels in the Nation's heavy-duty fleet.

1 INTRODUCTION: BACKGROUND AND OBJECTIVES

1.1 Safety Performance of the National Medium Duty/Heavy-Duty Vehicle Fleet and Technical Approach

The adoption and deployment of new fuel-efficiency (FE)-improving technologies is accelerating across Class 2b-8 MD/HDVs (Figure 1-1). Manufacturers, commercial truck and bus, and public transit bus fleets are implementing a diverse mix of FE technologies and alternative fuels so as to improve fuel efficiency in order to comply with Phase I of the NHTSA and EPA fuel efficiency and GHG emissions regulations for model years 2014-2018.[1]

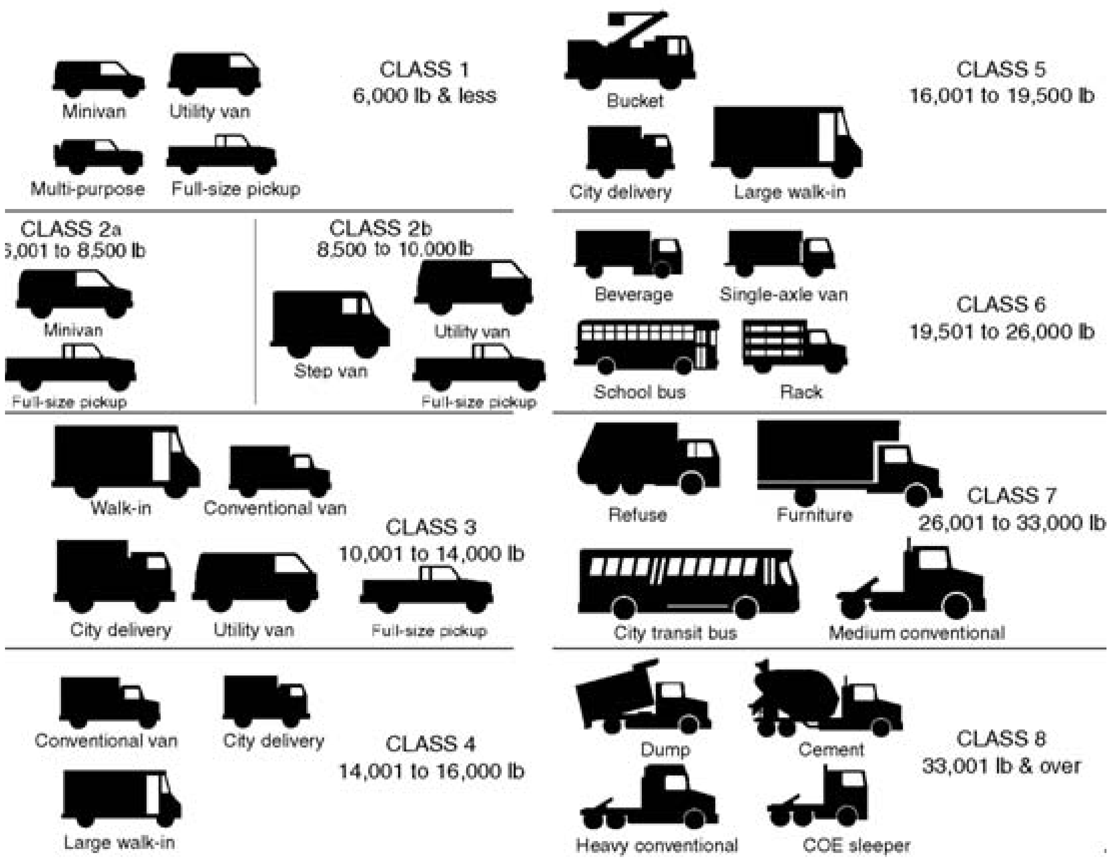

Figure 1-1: Medium and Heavy-Duty Vehicles Types by Gross Vehicle Weight Rating (GVWR).[2]

[1] See posted Sept 15, 2011 NHTSA and EPA final rule at CFR Volume 76, Number 179, Pages 57105-57513, www.gpo.gov/fdsys/pkg/FR-2011-09-15/html/2011-20740.htm

[2] Figure 1-1a from EPA/NHTSA Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Regulatory Impact Analysis

In 2010-2011, the baseline years of NHTSA/EPA rulemaking, heavy-duty vehicles represented only 4 percent of the national fleet, but consumed 20 percent of transportation fuel, and produced a similar fraction of GHG emissions as shown below in Figure 1-2[3].

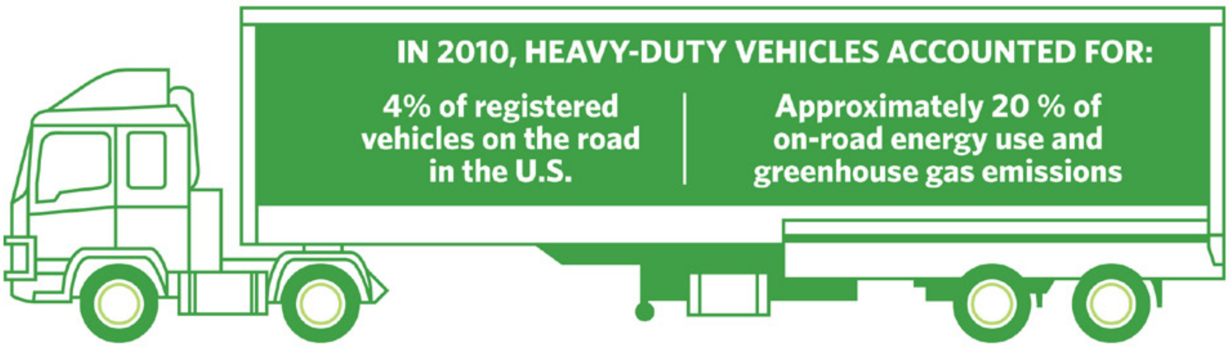

Figure 1-2: Heavy-duty vehicles share of national fleet, fuel consumption and GHG emissions

According to the DOT/BTS National Transportation Statistics[4], in 2011 the heavy-duty fleet consisted of over 10 million trucks, more than 666,000 commercial buses, and about 63,000 transit buses. According to the APTA2011 Public Transportation Factbook[5] over 35 percent of public transit buses used alternative power, including hybrid, electric, CNG, LNG and biodiesel blends.

A 2010 National Research Council report examined the technology options to improve fuel efficiency for all eight classes of MD/HD vehicles, covering a broad range of functions and duty cycles.[6] The report evaluated and ranked the FE technologies, also described in Chapter 2 of this report, by their potential fuel savings and associated emissions reduction for vehicle classes (Figure 1-3). It examined the costs and benefits of hybrid power trains (hydraulic, parallel, or series electric), advanced lithium-ion battery packs, power management electronics and software, hydrogen fuel cell auxiliary power units (APUs) used to extend range, electric motors, regenerative braking, idle reduction and automated start-stop, lightweight materials, fairings for improved aerodynamics, and single wide tires. The report also noted, but did not discuss in detail, the potential for safety impacts of these fuel efficiency-improving technologies for MD/HD vehicles when deployed either singly or in synergistic clusters. The fuel efficiency-

[3] Figure 1-1b source is the Feb. 2014 White House report: "Improving the Fuel Efficiency of American Trucks," at www.whitehouse.gov/sites/default/files/docs/finaltrucksreport.pdf
[4] See NTS Table 1-11 for 2010 and 2011 number of trucks and commercial and transit buses at www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html
[5] See www.apta.com/resources/statistics/Documents/FactBook/APTA_2011_Fact_Book.pdf
[6] See March 2010 NRC report "Technologies and Approaches to Reducing the Fuel Consumption of MDHD Vehicles."

improving technologies considered in the NRC report include EPA SmartWay tractor trailer technologies.[7]

The report also provided the technical underpinning for the 2011 medium- and heavy-duty regulation, and recommended that the agencies conduct a thorough evaluation of safety impacts associated with MD/HD efficiency technologies. Finding 6-15 of the NRC report stated that:

> "*There are potential safety issues associated with particular fuel reduction technologies. Examples are hybrids that use high-voltage batteries, or aerodynamic fairings that may detach from trucks on the road.*"

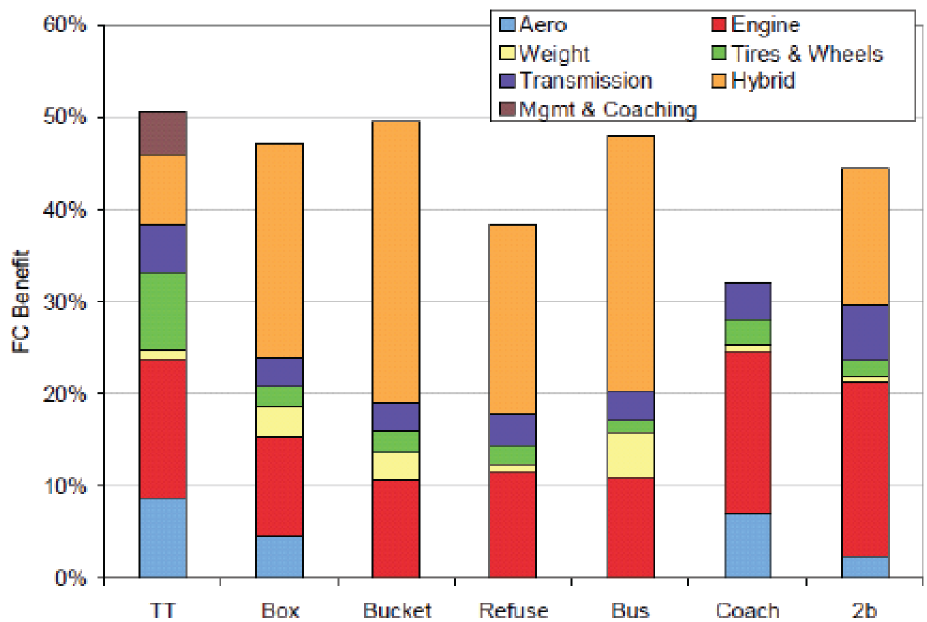

Figure 1-3: Relative potential fuel savings from six FE technologies applied to: tractor-trailers (TT), Class 3-6 box and bucket vehicles, transit buses and motor coaches; Class 8-refuse trucks; and Class 2b pickups and vans.[8]

An in-depth safety analysis of fuel efficiency-improving technologies for MD/HDV fleet-wide deployment can help inform future FE rulemaking for the medium- and heavy-duty fleet. In addition, it may help to identify and address potential gaps in safety regulations and standards, and enable the identification and prioritization of safety-focused research, while promoting fuel economy for environmental and economic benefits. The present study implements the NRC recommendation.

[7] See www.epa.gov/smartway/transport/what-smartway/verified-technologies.htm and www.epa.gov/smartway/technology/designated-tractors-trailers.htm

[8] Ibid.

The technical approach was to organize the literature review so as to facilitate a focused analysis of potential FE technology and alternative fuel safety impacts, and compile topically organized bibliographies extracted from an Excel database. This process facilitated the identification and analysis of potential safety issues related to specific FE technologies and alternative fuels adopted by vehicle fleets, and shed light on potential operator training and human factors safety issues. Over 500 references were reviewed and organized by topic (FE technology, alternative fuel, MD/HDV fleet employment and experience, regulations, safety, operational and human factors issues, etc.). The references were organized in a sortable Excel database, and are both footnoted and listed in Appendices 7.1-7.6 as topical Bibliographies: Safety; Fuel Efficiency Technology; Advanced Fuels; Operations/Human Factors; Regulatory Barriers; and Green Vehicle Deployment.

Relevant safety findings from the literature review are summarized in Chapter 2, and were complemented with inputs from focused interviews with a representative and diverse set of Subject Matter Experts (SMEs) with fleet management or engineering experience in the use of FE technologies and alternative fuels, as discussed in Chapter 3. Safety issues identified from Chapters 2 and 3 were then developed into the deterministic hazard scenarios described and analyzed in Chapter 4, including respective prevention and mitigation options. Chapter 5 then focused on the Federal and State regulatory framework affecting MD/HDV adoption of FEs and alternative fuels, with the goal of identifying residual regulatory barriers.

The key safety finding from this comprehensive review and analysis is that there are no major safety hazards preventing the adoption of FE technologies, nor from increased use of alternative fuels and vehicle electrification. Any identified safety concerns can be prevented or mitigated by complying with applicable regulations and safety standards and best practices and are being addressed by evolving technologies, such as electronic collision prevention devices.

1.2 National Heavy-Duty Fleet Crash Statistics and Trends

Approximately 5.7 million commercial motor vehicle (CMV) drivers were licensed in 2010. The FMCSA CMV fleet and crash statistics[9] show that in 2010 the national fleet was operated by 498,144 interstate freight carriers and included 846,051 buses operated by 11,701 interstate passenger carriers. In addition, public transit authorities operated over 63,000 buses in 2010. The public bus transit fleet used about 35 percent alternative power in 2010 and offered valuable experience with their safe operability. As illustrated below, the total number of alternative-fueled heavy-duty vehicles in the Nation's fleet in 2010 was under 70,000 -- a very small fraction of the conventional fleet.

Crash fatalities and injury totals and rates for trucks and buses, and other relevant safety performance annual statistics and trends are analyzed and reported annually by FMCSA and NHTSA, using data collected from States and analyzed by NHTSA's National Center for Statistics and Analysis (NCSA). Crash data provides safety performance trends over time in comparison with the Nation's entire vehicle fleet. The NCSA annual summaries,[10] and the

[9] See Commercial Motor Vehicle Facts (March 2013) at www.fmcsa.dot.gov/safety/data-and-statistics/commercial-motor-vehicle-facts-%E2%80%93-march-2013

[10] See NCSA Large Trucks 2012 data at www-nrd.nhtsa.dot.gov/Pubs/811868.pdf

FMCSA Motor Carrier Safety Progress Reports[11] (MCSPR) offer fleet-wide safety statistics that provide a useful context for examining the relative safety performance of the small fraction of "green fleets" of MD/HDVs so equipped. Filed field crash reports and analyses to date have not included any information on whether specific fuel efficiency technologies, or alternative fuels were involved as causal crash factors.

The NHTSA Fatality Analysis Reporting System (FARS) contains only records of fatal crashes and does not include census data for motor carriers. The FMCSA's MCMIS includes records of all crashes involving interstate and intrastate hazmat motor carriers, both fatal and non-fatal. Another difference is that the FMCSA Motor Carrier Management Information System (MCMIS) the Crash Rate is defined as to the Crash Count/Power Unit (PU)[12] Count * 1000, whereas in the FARS the fatality rate is defined as the number of fatalities normalized to 100 million vehicle miles travelled (VMT).

Crash figures and trends summarized by FMCSA[13] indicate a long term safety improvement trend : the total number of large trucks involved in fatal crashes decreased over a decade by 25 percent, and by 30 percent for crash injuries. Similarly, the number of buses involved in fatal crashes decreased by 16 percent. However, the rate of large truck and bus fatalities per 100 million VMT actually increased by 2 percent from 2010 to 2011.

Since the NHTSA/EPA MD/HDV fuel efficiency regulations have used 2010-11 as the regulatory fuel efficiency baseline years, this safety analysis also focused on crash safety performance data for the same period. Table 1-1 shows the 2009-2011 FMCSA number of truck crashes, fatalities and injuries. In 2009, NHTSA reported 3,380 fatalities from large truck crashes and only 254 from bus crashes, with 93,000 injured from both truck and bus crashes. Overall, the HDV fleet VMT in 2011 decreased from 2,966,506 million to 2,930,654 million compared to 2010, a decrease of 1.2 percent. Large truck crash fatalities and injuries, and the respective rates per 100 M VMT in 2010 and 2011[14] were compared to the national overall fleet rates: while the overall fleet fatality rate for the entire fleet fell to a historic low of 1.10 in 2011, the injury rate increased by 1.3 percent from 2010 to 2011. For large truck crashes however[15], there was a 1.9 percent increase in the number of people killed (from 3.686 in 2010 to 3,757 in 2011), with the corresponding fatality rate increase from 1.22 to 1.35.

Although there has been an increase in fatalities from large truck crashes from 2009 to 2011, large trucks continue to have a better relative safety record than the light-duty fleet: Total fatalities from large truck crashes rose from 3,380 in 2009 to 3,686 in 2010 (+9%), and 3,757 (+2%) in 2011. But the 2009 fatality rate for large trucks and buses was only 0.123 per 100 million VMT, compared to 1.14 for the entire fleet, including cars and light trucks. Similarly, the crash injury rate in 2009 for large trucks and buses was 3.15 per 100 million VMT, compared to 75.1 for the entire U.S. fleet. This superior CMV safety performance relative to privately owned light duty

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[11] See www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/MCSPR-09-30-13.pdf

[12] A power unit (PU) as defined by FMCSA is a truck or a bus, excluding trailers.

[13] See FMCSA "*Large Truck and Bus Crash Facts 2011* at www.fmcsa.dot.gov/safety/research-and-analysis/large-truck-and-bus-crash-facts-2011

[14] 2011 Motor vehicle crashes-an overview at www-nrd.nhtsa.dot.gov/Pubs/811701.pdf

[15] See NHTSA Traffic Safety Facts 2011 Data-Large Trucks at www-nrd.nhtsa.dot.gov/Pubs/811752.pdf

vehicles may be due to well-trained professional CMV drivers, and to frequently inspected and well-maintained vehicles.

In 2010, there were 3,341 fatalities and 56,000 injuries from large truck crashes (an increase of about 9 % relative to the 2009); and 247 fatalities and 12,000 injuries for buses. These 2010 NHTSA large truck crash statistics[16] (see also Table 1-1) show that, for the 10,770,054 large trucks registered and their risk exposure from 286,585 million VMTs, the large truck crash vehicle involvement rate was:

- 1.22 for 3,484 large trucks fatal crashes; and
- 20 for 58,000 trucks involved in injury crashes.

An updated FMCSA[17] analysis also summarized and compared 2009 through 2011 large truck crash totals and rates normalized to 100 million VMT. Although truck crash fatalities (Table 1-2) totals increased from 3,686 in 2010 to 3,757 in 2011 (by 1.9%) and so did injuries (by 15%), the associated fatality rate decreased modestly by 0.9 percent, while the injury rate increased by 1.3 percent. Large truck crashes resulted in 23,000 injuries in 2011, versus 20,000 in 2010, or a 15 percent increase. From 2011 to 2012, the number of large trucks involved in fatal crashes again increased by 5 percent, and the fatality rate per 100 million VMT increased by 4 percent.[18]

Table 1-1: FMCSA Safety Statistics 2009-2011.[19]

MCMIS SAFETY OUTCOMES*	CY 2009	CY 2010*	CY 2011*
CRASHES			
• Large Trucks and Buses	118,358	129,159	126,599
Large Trucks	105,457	115,730	113,775
Buses	13,310	13,856	13,261
FATALITIES			
• Large Trucks and Buses	3,803	4,202	3,935
Large Trucks	3,548	3,889	3,661
Buses	270	325	295
INJURIES			
• Large Trucks and Buses	74,242	80,230	77,348
Large Trucks	59,551	64,668	62,885
Buses	15,470	16,515	15,575

[16] See Table 36 in NHTSA "2010 Motor Vehicle Crash Data from FARS and GES" at www-nrd.nhtsa.dot.gov/Pubs/811659.pdf

[17] See "*Commercial Motor Vehicle (CMV) Facts- March 2013*" at www.fmcsa.dot.gov/safety/data-and-statistics/commercial-motor-vehicle-facts-%E2%80%93-march-2013

[18] See www.fmcsa.dot.gov/safety/data-and-statistics/large-truck-and-bus-crash-facts-2012

[19] See March 2012 Motor Carrier Safety Progress Report (MCSPR) at http://ebookbrowse.com/mcspr-03-31-12-pdf-d389813594

Table 1-2: Truck Fatalities in 2010-11

People Killed in Large-Truck Crashes

Type	2010	2011	Change	% Change
Truck Occupants	530	635	+105	+20%
Single-Vehicle	339	403	+64	+19%
Multivehicle	191	232	+41	+21%
Other Vehicle Occupants	2,797	2,695	-102	-3.6%
Nonoccupants	359	427	+68	+19%
Total	3,686	3,757	+71	+1.9%

Source: FARS 2010 (Final), 2011 (ARF)

This report focuses on the relative safety performance of the currently very small fraction of heavy-duty vehicles in the fleet that have adopted fuel efficiency technologies, or alternative fuels (CNG, LPG, biodiesel, hybrid-electric and electric). In attempting to link FE technologies and driver training to the safety of advanced vehicles relative to the overall fleet, it is important to examine the causes contributing to large trucks crashes. Table 1-3 summarizes the findings from the 2007 FMCSA Large Trucks Crash Causation Study (LTCCS). Causative factor analysis showed that over 90 percent of crashes are due to human factors, such as driver distraction or error, highlighting the importance of driver fitness and training. Only 10 percent of crashes were vehicle-related, so any safety incidents attributable to FE technologies and/or alternative fuels would be included in this category.

Table 1-3: Estimated Numbers of Trucks in All Crashes, by Critical Reasons[20]

Critical Reasons	Number of Trucks	Percent of Total
Driver	**68,000**	**87%**
Non-Performance	9,000	12%
Recognition	22,000	28%
Decision	30,000	38%
Performance	7,000	9%
Vehicle	**8,000**	**10%**
Environment	**2,000**	**3%**
Total Number of Large Trucks Coded with Critical Reason	**78,000**	**100%**
Total Number of Large Trucks Not Coded with Critical Reason	63,000	—
Total Number of Large Trucks Involved in Crashes	**141,000**	—

[20] See Analysis Brief of FMCSA Large Truck Crash Causation Study (2007) at www.fmcsa.dot.gov/facts-research/research-technology/analysis/FMCSA-RRA-07-017.htm; LTCCS Table Notes: Results shown are national estimates for the 141,000 large trucks estimated to have been involved in fatal and injury crashes during the study period. The estimates may differ from true values, because they are based on a probability sample of crashes and not a census of all crashes. Estimates are rounded to the nearest 1,000 large trucks.

The total number of alternatively-fueled trucks and buses in the U.S. fleet, and their current fuel consumption and fuel efficiency were extracted from annual Department of Energy (DOE) publications.[21] Table 1-4 and Table 1-5 provide Energy Information Administration (EIA) statistics[22] on the number of MD/HD Alternative Fuel Vehicles (AFVs) in use for 2010 and 2011, respectively, by fuel type and weight class.

Table 1-4: Alternative-Fuel Vehicles in Use by Fleet Operators: 2010[23]

	Light Duty	Medium Duty	Heavy Duty	Total
Ethanol — Flex Fuel	592,231	26,255	18	618,504
Natural Gas — Total	67,296	22,575	28,976	118,847
Compressed Natural Gas	67,296	22,521	26,000	115,817
Liquefied Natural Gas	0	54	2,976	3,030
LPG — Propane	76,694	27,771	36,057	140,522
Electric — Battery	56,566	86	779	57,451
Total	792,787	76,687	65,850	935,324

Table 1-5: Alternative-Fuel Vehicles in Use 2011 by Weight Class and Fuel Type[24]

	Light Duty	Medium Duty	Heavy Duty	Total
Ethanol — Flex Fuel	819,133	43,387	317	862,837
Liquid Petroleum Gas (Propane)	76,647	26,855	35,975	139,477
Natural Gas	66,147	23,473	32,030	121,650
Compressed Natural Gas	65,980	23,343	28,891	118,214
Liquefied Natural Gas	167	130	3,139	3,436
Electric — Battery	66,409	87	779	67,295
Hydrogen	425	1	101	527
Total	1,028,761	93,803	69,222	1,191,786

[21] Current Annual *Transportation Energy Data Book* posted at www.cta.ornl.gov/data
[22] See Alternatives to Traditional Transportation Fuels 2010 Report Table at www.eia.gov/tools/faqs/faq.cfm?id=93&t=4
[23] See www.eia.gov/renewable/afv/index.cfm
[24] See Alternatives to Traditional Transportation Fuels 2011 report at www.eia.gov/renewable/afv/index.cfm

An APTA study found that as of January 2011 over 35 percent of public transit buses used alternative fuels (such as CNG or hybrid electric technology), and the adoption rate of fuel efficiency technologies has been accelerating.[25] Recent DOE data[26] on MD/HDVs show that trucks consumed 2,901,000 barrels per day or 21.4 percent of total transportation fuel use, while buses consumed 95.0 bblpd, representing only 0.7 percent of total transportation fuel use. The Class 8 trucks had the highest annual fuel use of about 13,000 GGE/year, followed by transit buses with 10,800 GGE/year, and refuse trucks with 10,000 GGE/year. The total for delivery trucks and school buses combined was 2,000 GGE/year. The DOE number of MD/HDVs by type, and fuel efficiency included:

- 8,356 registered single unit trucks with an average FE of 7.4 mpg;
- 2,617 combination trucks with average FE of 6 mpg; and
- 850,000 buses in the United States, of which 650,000 are school buses and the rest are intercity buses and 65,363 transit buses averaging 7.1 mpg.[27]

The DOE Alternative Fuels Data Center (AFDC) case studies and the "Clean Cities Guide to Alternative Fuel and Advanced Medium and Heavy-Duty Vehicles[28]"discuss truck and bus fleets that successfully converted to, or adopted alternative fuels (CNG, LNG, biofuels) or hybrid-electric propulsion.[29] The DOE National Clean Fleets Partnership enlisted 28 of the largest corporate commercial fleet owners/operators, that successfully adopted FE technologies and/or alternative fuels, as discussed in a safety context in Sections 2 and 3.[30]

The rate of adoption over time for various FE technologies by truck fleets was studied by NACFE in annual benchmark reports[31] focused primarily on cost recovery through fuel savings and operational efficiency gains, along with barriers to increased fleet penetration, but did not address potential safety issues.[32] NACFE annual surveys of "green" freight truck fleet managers were focused only on benchmarking large fleets adoption rates of, and payback time for FE technologies. NACFE adoption trends reported for specific FE technologies are also shown in Figure 2-12 and further discussed in Chapter 2. Similarly, CalHEAT, the California truck research center, conducted recent surveys of truck fleets regarding the market barriers to adoption of FE technologies and alternative fuels,[33] again without addressing any associated potential safety concerns. Literature resources reviewed and findings on potential safety issues

[25] See www.apta.com/mediacenter/pressreleases/2013/Pages/130422_Earth-Day.aspx
[26] Posted DOE AFV data at: www.afdc.energy.gov/data/tab/all/data_set/10308
[27] See BTS table www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_15.html
[28] See www.afdc.energy.gov/uploads/publication/medium_heavy_duty_guide.pdf
[29] See www.afdc.energy.gov/case
[30] See www.afdc.energy.gov/uploads/publication/60619.pdf
[31] See NACFE-ICCT 2013 report at www.theicct.org/sites/default/files/publications/ICCT-NACFE-CSS_Barriers_Report_Final_20130722.pdf
[32] See http://nacfe.org/ postings
[33] See CalHEAT "Market Barriers And Opportunities For Alternative Fuel-Hybrid Systems" June 2013 at www.calstart.org/Libraries/CalHEAT_2013_Documents_Presentations/CalHEAT_Market_Barriers_and_Opportunities_for_Alternative_Fuel-Hybrid_Systems.sflb.ashx

associated with MD/HDV fleet adoption of FE technologies and alt-fuels are discussed below in Chapter 2.

In conclusion, although the national heavy-duty motor vehicles crash statistics for 2010-2011 provide average baseline for fleet safety performance, these statistics could not be used for a safety analysis of specific FE technologies due to the lack of such information in crash field reports, and due to the very small number of such vehicles compared to the conventional MD/HDV fleet.

A preliminary analysis of large trucks and bus crashes in 2010-2011 was conducted as part of this study to compare crash rates of conventional CMVs to the few FE–equipped "green" fleets. However, the small percentage of hybrid, electric, and alternative-fuels vehicles in the overall fleet resulted in an analysis that would rely on the statistics of small numbers. Therefore, comparisons between the crash rates of conventional fleets and green fleets was deemed inadvisable. Analysis over a longer time period, or after a larger penetration of FE technologies and/or alternative fuels occurs in the MD/HDV fleet, may allow for statistically meaningful comparisons.

2 REVIEW OF LITERATURE ON ADOPTION OF FE TECHNOLOGY CLUSTERS, ALTERNATIVE FUELS, AND OPERATIONAL SAFETY OF MD/HDV FLEETS

2.1 Introduction

A comprehensive literature survey was conducted to identify any MD/HDV safety issues regarding existing and emerging FE technologies and alternative fuels. Resources reviewed included research reports, technical articles, and news items posted on the Internet; conference proceedings and presentations; annual statistical data on truck and bus safety and energy consumption; Congressional hearings, and trade association surveys and testimonies, etc. The report focus was on extracting any MD/HDV safety information specific to the NHTSA and EPA-approved FE technologies from key sources (e.g., EPA SmartWay, DOE Advanced Vehicle Technologies- AVT and 21st Century Truck, DOD/TARDEC, CALSTART, and NRC FE technology reports); crash safety from IIHS, NHTSA, and FMCSA MCMIS databases; FHWA reports on extra-heavy trucks and trailers; regulatory information from the NHTSA R&D and regulatory plan, commercial fleet truck and bus trade associations; Congressional testimony; newsletters, etc.).

The bibliography database, comprising over 500 references, was organized as an Excel spreadsheet, which can be "filtered" by category to facilitate data mining and retrieval by topic (vehicle safety, FE technology, alt-fuels, operational best practices, regulatory documents). Separate bibliographies were compiled by topic, i.e., specific FE technology applied to MD/HDVs, safety statistics and analyses, alternative fuels, operational and behavioral issues, and green fleet vehicle deployment. (See Appendices 7.1 to 7.6.) Sections 2.2-2.9 describe the literature findings on MD/HDV safety issues, organized by the specific FE technology and/or alternative fuel wherever possible. References cited relating to MD/HDV fleet deployment of specific FE technologies and alternative fuels provide the general overview of their current adoption and penetration. However, most references offer little to no quantitative statistical data regarding potential hazards, and only sparse evidence regarding the safety impacts of individual FE technologies, alternative fuels, and related driver operation factors.

2.2 Adoption of Alternative Clean Fuels

2.2.1 Natural Gas Benefits and Safety Issues

Natural gas is a domestically produced gaseous fuel readily available through the utility infrastructure. It is an odorless, nontoxic, gaseous mixture of hydrocarbons—predominantly methane (CH_4), which must be odorized for leaks to be detectable. At high concentrations it is a potential asphyxiant, as well as a fire or explosion hazard; methane is also a powerful Greenhouse Gas (GHG). Because of the gaseous nature of this fuel, it must be stored onboard a vehicle either as compressed natural gas (CNG) or liquefied natural gas (LNG).[34]

[34] DOE EERE. 2012d. National Clean Fleets Partnership www1.eere.energy.gov/cleancities/national_partnership.html

CNG is used in light-, medium-, and heavy-duty applications. To provide adequate driving range, it is stored onboard a vehicle in cylinders at a pressure of 3,000 to 5,000 pounds per square inch (psi). The AFDC states that a CNG-powered vehicle has approximately the same fuel economy as a conventional gasoline vehicle on a gasoline-gallon-equivalent (GGE) basis.[35]

LNG is produced by purifying natural gas and super-cooling it to -260°F to turn it into a liquid. Because it must be kept at cold temperatures, LNG is stored in double-walled, vacuum-insulated pressure vessels at up to 230 psi. LNG is good for trucks needing a longer range because liquid is more dense than gas (CNG) and more energy can be stored by volume in a given tank. LNG is typically used in medium- and heavy-duty vehicles. A GGE equals about 1.5 gallons of LNG.

Propane is another hydrocarbon alternative fuel (C_3H_8) fuel sometimes referred to as liquefied petroleum gas (LPG) or autogas. It is produced domestically from both natural gas processing and crude oil refining. It is also nontoxic, colorless, and virtually odorless. As with natural gas, an identifying odor is added so the gas can be readily detected.

2.2.1.1 Penetration/Adoption

CNG vehicles are currently more commonplace than LNG vehicles. Using CNG as fuel is currently best suited for vehicles that are housed and fueled at a common location, such as public transit vehicles, refuse trucks, and delivery fleets because of refueling infrastructure and special handling requirements. Modest growth of CNG fueling stations has been spurred by the Energy Policy Act of 1992, and demand is expected to rise further.[36] However, even though the United States has about 180,000 gasoline stations, there are only about 1,000 CNG stations, with only half open to the public.[37]

Large vehicles are necessary to accommodate the cryogenic fuel tanks used to store LNG, which are 70 percent larger by volume than a comparable diesel tank. (Compressed gas needs about six times as much space as diesel, even when squeezed down to 3,000 psi.) LNG systems are typically more expensive than CNG systems, as is the fuel itself, but LNG vehicles can exceed 300 miles before needing to be refueled, in contrast to CNG vehicles. Therefore, LNG is considered an alternative for both long-haul (thousands of miles) and short-haul (hundreds of mile) trucking. However, until LNG infrastructure is commonplace, it is unlikely to become a widespread alternative fuel.[38]

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[35] See Natural Gas Fuel Basics: 1 GGE equals about 5.66 pounds of CNG, at www.afdc.energy.gov/fuels/natural_gas_basics.html

[36] Carbon War Room Research & Intelligence Group. 2012. Unlocking fuel-saving technologies in trucking and fleets http://carbonwarroom.com/sites/default/files/reports/Unlocking%20Fuel%20Saving%20Technologies%20in%20Trucking%20and%20Fleets%20(Carbon%20War%20Room).pdf

[37] Garthwaite, J. 2011. Trading Oil for Natural Gas in the Truck Lane http://news.nationalgeographic.com/news/energy/2011/09/110902-natural-gas-fuel-for-trucks

[38] See Carbon War Room Research & Intelligence Group. 2012. Unlocking fuel-saving technologies in trucking and fleets http://carbonwarroom.com/sites/default/files/reports/Unlocking%20Fuel%20Saving%20Technologies%20in%20Trucking%20and%20Fleets%20(Carbon%20War%20Room).pdf

Even though natural gas has long been used to power vehicles, only about 0.1 percent of current U.S. natural gas production is currently used for transportation fuel.[39] According to NGV America, a trade association, the amount of diesel fuel currently used annually for highway travel is equivalent to six trillion cubic feet of natural gas. Current national natural gas demand is in the range of 22 trillion cubic feet a year, suggesting that the diesel use could in principle be displaced by natural gas.

Compressed natural gas (CNG) consumption for transportation has increased steadily since 1995, as shown in Figure 2-1. As discussed in Section 2.2.3, the use of propane, which was the most common alternative vehicle fuel in the early 1990s, has trended downward as CNG (and to a lesser extent LNG) has become more popular.

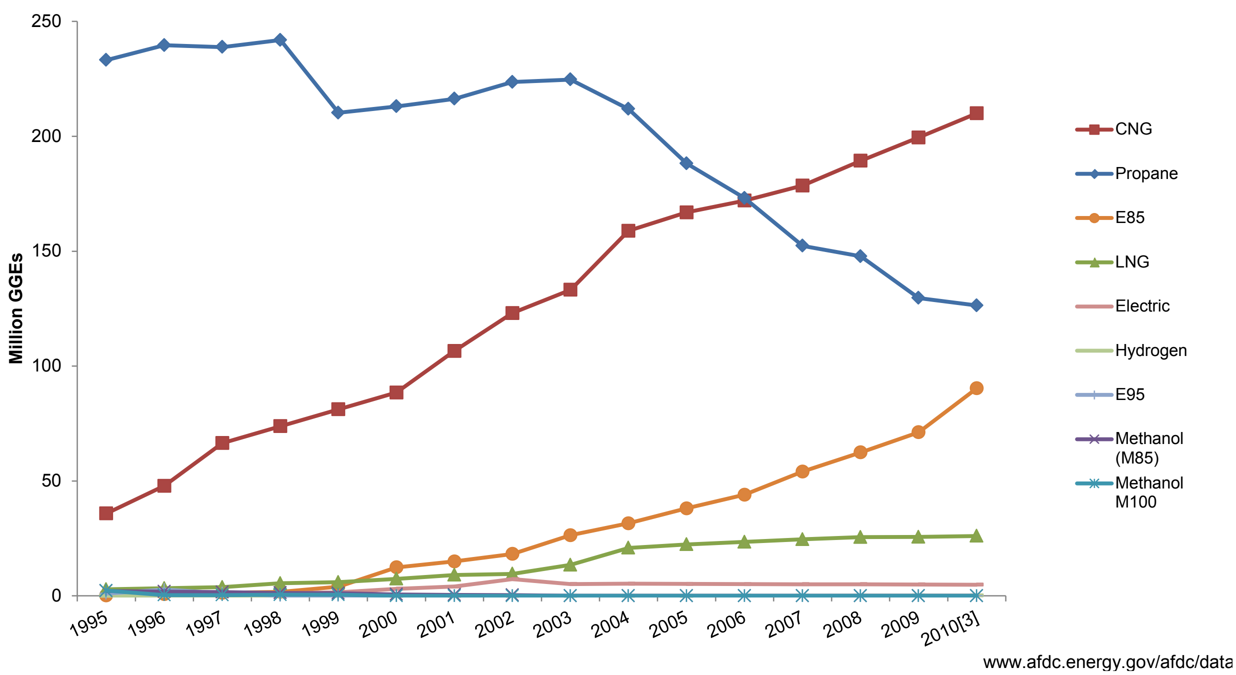

Figure 2-1: Estimated Consumption of Alternative Fuel by AFVs in the United States (Ref. 15)

Natural gas vehicles have been in use in the United States since the early 1970s, especially by urban transit bus "clean" fleets, and, to a lower extent, by personal or fleet dual-fueled vehicles, i.e., vehicles that can operate on two different fuels. By 2010, there were 115,863 CNG and 3,354 LNG vehicles across all weight classes in the United States (Figure 2-2), which amounts to less than one percent of the 15 million NGVs globally, the vast majority of which are light-duty vehicles.[40,41] A total of 43,088 commercial vehicles were using natural gas in 2010, of which approximately 35,000 were medium or heavy duty.

[39] DOE/EERE 2012, Alternative Fuels and Advanced Vehicles Data Center (AFDC), www.afdc.energy.gov/afdc/fuels/natural_gas.html
[40] Ibid.

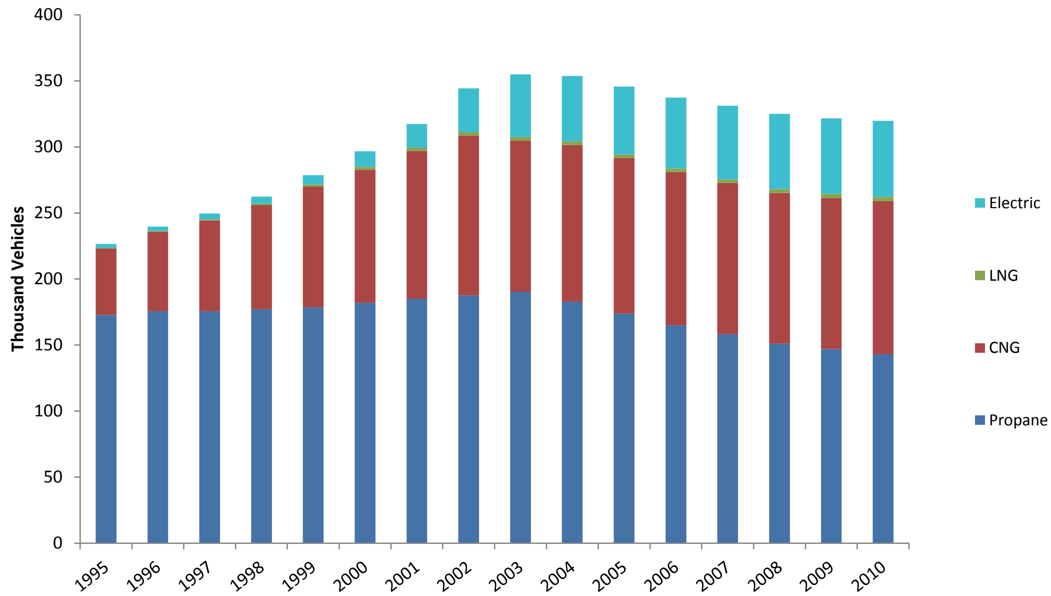

Figure 2-2: Alternative Fueled Vehicles in Use in the United States[42]

Adoption of natural gas in transit bus fleets increased rapidly in the late 1990s, growing from 2.8 percent of buses in 1996 to 18.6 percent in 2011. More than 40 North American transit agencies now use buses powered by CNG. In 2011, the Los Angeles County Metropolitan Transportation Authority became the first major U.S. transit agency with a fleet 100 percent equipped with alternative fuel technologies—almost all CNG. [43]

The 21,510 natural gas-powered transit buses comprise almost two-thirds of U.S. MD/HDV NGVs.[44] In heavy-duty vehicles, both dedicated natural gas and dual-fuel, compression-ignited engines are available. The dual-fuel engines are slightly more fuel-efficient than the spark-ignited dedicated engines, but they also increase the complexity of the fuel storage system by requiring storage of both types of fuel. [45]

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[41] Carbon War Room Research & Intelligence Group. 2012. Unlocking fuel-saving technologies in trucking and fleets
http://carbonwarroom.com/sites/default/files/reports/Unlocking%20Fuel%20Saving%20Technologies%20in%20Trucking%20and%20Fleets%20(Carbon%20War%20Room).pdf
[42] DOE EERE. 2012a. Alternative Fuels and Advanced Vehicles Data Center
www.afdc.energy.gov/afdc/fuels/natural_gas.html
[43] Gentry, W. 2012. Statement of William Gentry, President, Gentry Trailways and on behalf of American Bus Association and United Motorcoach Association Subcommittee on Highways and Transit, House Transportation and infrastructure Committee, U.S. House of Representatives
http://republicans.transportation.house.gov/Media/file/TestimonyHighways/2012-09-13-Gentry.pdf
[44] Kwan, Q. 2012. Safety Considerations Related to Commercial Vehicles Using Natural Gas
www1.eere.energy.gov/cleancities/pdfs/ngvtf12_kwan.pdf
[45] DOE EERE. 2012a. Alternative Fuels and Advanced Vehicles Data Center
www.afdc.energy.gov/afdc/fuels/natural_gas.html

LNG has not been widely deployed in transit systems to date,[46] although over 1,000 transit buses were operational in 2003 with seven public transit agencies operating LNG powered buses.[47]

According to the DOE Alternative Fuels and AFDC, there were 836 public and private CNG stations and 38 LNG stations in the United States as of June 2, 2010.

Examples of significant adoption of natural gas by truck fleets include those below:

- **United Parcel Service (UPS)** operates about 1,100 vehicles running on LNG or compressed natural gas (CNG in its global fleet, including about 60 LNG heavy tractor trucks.[48] These new vehicles will reduce greenhouse gas emissions by 25 percent compared to the older generation diesel trucks they replaced. The original demonstration fleet of 11 vehicles shuttling between California and Las Vegas showed UPS that LNG trucks could handle demanding situations like hauling multiple trailers over mountain ranges.[49] Out of its 17,000 tractor-trailers, UPS would like to convert 1,000 to liquefied natural gas, depending on the availability of refueling infrastructure. UPS is also using propane, electric and hybrid electric vehicles to help the company reach its 20 percent mpg improvement goal for the entire U.S. package delivery fleet between 2000 and 2020.[50]
- **Waste Management** has over 1,000 LNG trucks in its fleet. A third of its California fleet is fueled by LNG derived from the decomposition of organic waste in the company's Altamont Landfill in Livermore, California. Waste Management has CNG and LNG fueling stations at 17 of its facilities throughout North America with more under development.[51] Waste Management began operating a fleet of heavy-duty refuse trucks powered by LNG in Pennsylvania as early as 1997. This implementation was considered successful, although the LNG trucks had a 9 percent to 12 percent lower fuel economy versus diesel. [52]
- **South Coast Air Quality Management District (SCAQMD)** Heavy-Duty Natural Gas Drayage Truck Replacement Program in California purchased 219 LNG trucks in 2008,

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46 Friedman, D. M., & Malcosky, N. D. 1996. Liquefied Natural Gas Safety in Transit Operations: Final Report http://trid.trb.org/view.aspx?id=713273

47 See www.afdc.energy.gov/pdfs/mod04_lng.pdf and Gentry, W. 2012. Statement of William Gentry, President, Gentry Trailways and on behalf of American Bus Association and United Motorcoach Association Subcommittee on Highways and Transit, House Transportation and infrastructure Committee, U.S. House of Representative http://republicans.transportation.house.gov/Media/file/TestimonyHighways/2012-09-13-Gentry.pdf

48 "UPS press release Feb.22, 2011 "UPS Clearing the air with new LNG tractors" at www.pressroom.ups.com

49 Wald, M. 2011. U.P.S. Finds a Substitute for Diesel: Natural Gas, at 260 Degrees Below Zero http://green.blogs.nytimes.com/2011/02/22/u-p-s-finds-a-substitute-for-diesel-natural-gas-at-260-degrees-below-zero/

50 Environmental Leader. 2011. UPS Adds to its Natural Gas Truck Fleet www.environmentalleader.com/2011/02/25/ups-adds-to-its-natural-gas-truck-fleet

51 Work Truck Magazine. 2011. Waste Management Adds 1,000th Natural Gas Truck to Fleet www.worktruckonline.com/Channel/Fuel-Management/News/Story/2011/07/Waste-Management-Adds-1-000th-Natural-Gas-Truck-to-Fleet.aspx

52 Clark, K. C. P. N. N. 2001. Waste Management's LNG Truck Fleet Final Results www.afdc.energy.gov/pdfs/waste_lng_final.pdf stated: "This fuel economy result shows considerable improvement compared to other heavy-duty natural gas engine products."

all of which were scheduled to be deployed by the end of 2012. These heavy-duty trucks completed 5.3 million LNG-powered miles by the end of 2011.[53]

- **Green Energy Oilfield Services** operates 60 LNG-powered vacuum and winch trucks supporting its gas drilling operations.[54]
- **AT&T's** fleet of 73,500 vehicles includes 3,000 NGVs, and by 2013, the company reportedly plans to increase the number of natural gas vehicles to 8,000.[55]

According to a recent economic report, the widespread fleet adoption of LNG heavy-duty trucks still faces hurdles, including the scarcity of LNG retail outlets, refueling infrastructure stations, uncertainty over future governmental support, and the need for new training and logistics. Further study in the areas of hardware maintenance, availability of replacement parts, and the long-term durability of cryogenic fuel tanks would enable better long-term assessments of potential safety effects.[56]

2.2.1.2 Benefits

Natural gas vehicles (NGVs) have similar power, acceleration, and cruising speed to gasoline or diesel vehicles. The driving range of NGVs is generally lower than that of comparable gasoline and diesel vehicles because less energy content can be stored in a natural gas tank of the same size as that of gasoline or diesel fuels. Extra natural gas storage tanks, or the use of LNG instead of CNG, can increase the range for large vehicles. However, this imposes a fuel economy penalty due to the added weight and reduces the amount of useable space in a vehicle.[57] A bus with an LNG fuel system weighs approximately 1,000 pounds less than one with a CNG fuel system and has a longer range. One gallon of LNG contains about 60 percent of the energy in a gallon of diesel fuel, while CNG at 3,600 pounds per square inch (psi) pressure contains only about 30 percent.

Natural gas burns cleaner than gasoline or diesel, and it can help ensure compliance with the EPA Clean Air and the recent NHTSA/EPA MD/HDV fuel efficiency and GHG emissions rules. Natural gas offers life cycle GHG emissions benefits over conventional fuels, as well as a reduction in EPA regulated tailpipe emissions.[58]

Assessments of the greenhouse gas benefits of natural gas fuels vary, but they generally show that on an energy basis (grams per million BTU or grams per megajoule) CNG has 15-20 percent

[53] DOE EERE. 2012c. Largest U.S. Port Complex Embraces LNG for Heavy-Duty Trucks www.afdc.energy.gov/case/1203
[54] Work Truck Magazine. 2012. Green Energy Oilfield Services Builds Green Truck Fleet www.worktruckonline.com/News/Story/2012/02/Green-Energy-Oilfield-Services-Builds-Green-Truck-Fleet.aspx
[55] Garthwaite, J. 2011. Trading Oil for Natural Gas in the Truck Lane http://news.nationalgeographic.com/news/energy/2011/09/110902-natural-gas-fuel-for-trucks/
[56] Oil and Gas Journal. 2012. LNG seen viable fuel for heavy-duty trucks www.ogj.com/articles/2012/06/lng-seen-viable-fuel-for-heavy-duty-trucks.html
[57] Friedman, D. M., & Malcosky, N. D. 1996. Liquefied Natural Gas Safety in Transit Operations: Final Report http://trid.trb.org/view.aspx?id=713273
[58] DOE EERE. 2012a. Alternative Fuels and Advanced Vehicles Data Center www.afdc.energy.gov/afdc/fuels/natural_gas.html

lower GHG emissions than diesel fuel, while LNG has 3-9 percent lower GHG emissions.[59] The lower benefits from LNG are due to a higher energy requirement for liquefaction of LNG compared to compression of CNG. However, natural gas engines typically have lower efficiency than diesel engines, so some of the GHG benefit of natural gas fuels is reduced in practice, i.e., per-mile GHG reductions from the use of natural gas fuels instead of diesel will be lower due to greater fuel use per mile. In the future, these benefits may increase if natural gas supplies are blended with renewable natural gas captured from the natural decay of organic materials, e.g., in landfills. This biomethane could reduce life cycle carbon emissions by 85-90 percent when compared with diesel and gasoline, as shown in Figure 2-3.[60]

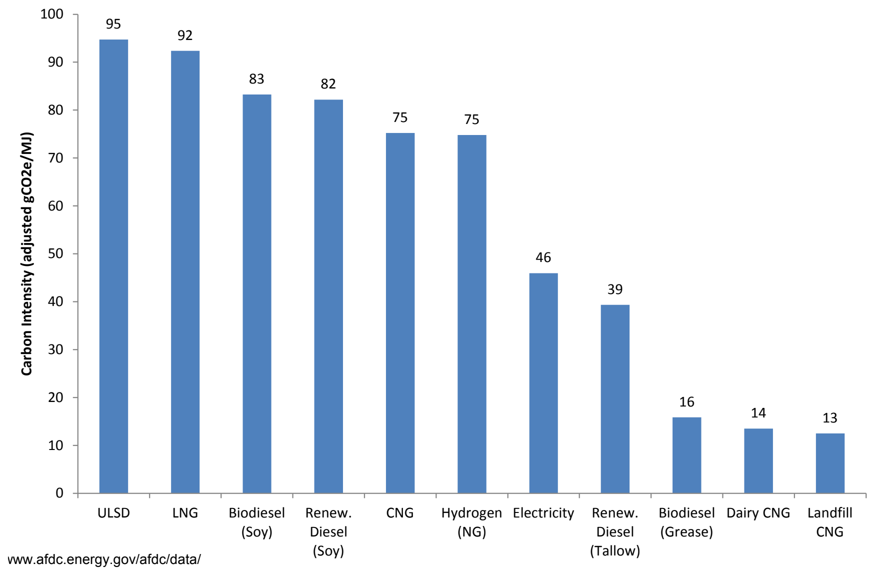

Figure 2-3: Carbon Intensity of Various Fuels in California HDVs. [61]

2.2.1.3 Safety Considerations of CNG-Fueled MD/HDVs

Since LNG and CNG tanker trucks are considered hazardous material transport, they are regulated by PHMSA and were not considered in this literature review. Only the crash rates of vehicles propelled by natural gas were considered.

Natural gas has certain safety advantages compared to gasoline and diesel: it is non-toxic, lighter than air, and dissipates rapidly when released. An odorant is added to provide a distinctive smell that is easy to recognize, and it is detectable at 20 percent of the lower flammability limit.[62] Unlike diesel and gasoline leaks, which puddle on the ground and can create an on-going hazard

[59] Argonne National Laboratory Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, https://greet.es.anl.gov/

[60] Natural Gas Vehicles for America. 2012. NGVs and the Environment www.ngvc.org/about_ngv/ngv_environ.html

[61] DOE EERE. 2012a. Alternative Fuels and Advanced Vehicles Data Center www.afdc.energy.gov/afdc/fuels/natural_gas.html

[62] Clean Vehicle Education Foundation. 2010. How Safe are Natural Gas Vehicles? www.cleanvehicle.org/committee/technical/PDFs/Web-TC-TechBul2-Safety.pdf

over a wide area, leaking natural gas tends to rise and dissipate to non-hazardous levels quickly, with only a short, vertical column directly above the leak in which the gas mixture is flammable. Natural gas leaks therefore pose little fire or explosion risk if the gas is leaking into open air. However, if the leak is into an enclosed space (either a building or an enclosed space on the vehicle) the resulting fire and explosion hazard can be significant, depending on the size of the leak.

While natural gas is non-toxic, it can displace the air in a pit, and/or reduce oxygen concentration levels, and potentially pose an asphyxiation hazard to workers. Hazards relating to CNG also include fire, thermal explosion if release is into an enclosed space, and mechanical rupture of pressure vessel. Gas release can occur from a fuel system leak or from activation of a PRD. Ignition can also result from contact with hot surfaces, open flames, and sparks, including static electricity.[63] There are four basic types of CNG tank designs: Type 1- all steel, Type 2- metal liner with hoop wrapped composite; Type 3 metal liner with fully wrapped composite; and Type 4- plastic liner with fully wrapped composite (glass fiber or carbon fiber may be used). Onboard CNG storage tank pressures range from 250 bars, 350 bars, to 700 bars, but all must have pressure relief valves.

At a CNG fueling station, the gas is compressed before being supplied to vehicles at 3,000 to 3,600 psi. This stored energy represents a potential hazard not found in unpressurized diesel or gasoline fuel tanks. CNG fuel tanks can release significant energy if the tank suddenly fails. Such failures are rare, but have occurred. According to one database, between 2000 and 2008 there were only 26 CNG cylinder failures worldwide, which is a very small dataset for predictive failure analysis.[64] Figure 2-4 lists the causes of these failure incidents. The leading causes of catastrophic cylinder ruptures were vehicle fires and environmental damage, such as corrosion. Several ruptures occurred when exposure to a fire on board the vehicle failed to activate the cylinder Pressure Relief Devices (PRDs), and the cylinder pressure increased until explosion.

Safety in the design and operation of the CNG refueling infrastructure is partly addressed by National Fire Protection Association (NFPA) Code 52, *Vehicular Gas Systems Code,* which requires minimum venting rates for indoor facilities as well as pressure relief devices on all storage systems that discharge to a sufficiently vented indoor or to an outdoor area. There is also a recommended practice from the Society of Automotive Engineers, SAE J2406, *Recommended Practices for CNG Powered Medium and Heavy-Duty Trucks*. Both of the above are voluntary.

A 2005 probabilistic risk assessment study of CNG bus safety[65] concluded that CNG buses were 2.5 times more prone to fire fatality risk than diesel buses. The study also estimated that CNG bus passengers were at up to two orders of magnitude increased fire fatality risk: an estimated 0.16 fatalities per 100-million miles compared to (based on historical data) 0.0007 per 100-million miles for diesel school buses. This study used historical component failure data from the

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[63] NHTSA. 2010a. Study of Heavy Truck S-Cam, Enhanced S-Cam, and Air Disc Brake Models Using NADS www.nhtsa.gov/DOT/NHTSA/NVS/Vehicle%20Research%20&%20Test%20Center%20(VRTC)/ca/capubs/811314.pdf

[64] Wong, J. 2009. CNG & Hydrogen Tank Safety, R&D, and Testing www1.eere.energy.gov/hydrogenandfuelcells/pdfs/cng_h2_workshop_8_wong.pdf

[65] "Compressed natural gas bus safety: a quantitative risk assessment," by S. Chamberlain and M. Modarres, in Risk Analysis, April 2005, vol25(2) 377-387, at www.ncbi.nlm.nih.gov/pubmed/15876211

aerospace and process industries to estimate the frequency and consequences of different fire and explosion scenarios. One major limitation of this analysis was its reliance on generic component failure data rather than on CNG-specific hardware failure data. The analysis also did not attempt to model the physics of fatigue and corrosion failure modes of these components, which would be needed to increase the accuracy of the estimates.

A 2010 Clean Vehicle Foundation survey of 8,331 natural gas utility, school bus, municipal, and business fleet NGVs that traveled 178.3 million miles[66] indicated that the injury rate was 37 percent lower than the gasoline fleet vehicle injury rate. The study also reported no fatalities compared with 1.28 deaths per 100 million miles for gasoline fleet vehicles. The reported collision rate for NGV fleet vehicles was 31 percent lower. NGVs were involved in seven fire incidents, with only one incident directly attributable to failure of the natural gas fuel system.[67] This study indicates that NGVs may operate more safely than gasoline or diesel vehicles.

Ten transit agencies, representing 4,071 CNG buses, reported that the mean time between failures (MTBF) for their CNG buses ranged from 58 percent to 80 percent of diesel buses, indicating lower reliability, although not necessarily lower safety.[68] The potential safety issues that respondents raised were fire safety, explosion, and toxicity and health. However, most respondents did not consider the fire risk of CNG higher than that of diesel.

Another survey of recent transit industry practice drew on seven transit agencies, which stated that their CNG buses performed well and have achieved broad public acceptance. Differences between agencies in hazard and consequence mitigation measures were noted, such as inconsistent implementation of methane monitoring in CNG bus facilities, procedures and actions to detect methane, and comprehensive control of strong ignition sources.[69]

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[66] Adams, R. and D.B Horne, 2010b. “CNG Transit Experience Survey 2009-2010” (Clean Vehicle Education Foundation and NREL report NREL/SR-7A2-48814
September 2010) at www.afdc.energy.gov/pdfs/48814.pdf
Adams, R. 2010b. CNG Transit Experience Survey (Clean Vehicle Education Foundation)
www1.eere.energy.gov/cleancities/pdfs/ngvtf10_trans_lessons_learned.pdf

[68] Adams, R. 2010b. CNG Transit Experience Survey (Clean Vehicle Education Foundation)
www1.eere.energy.gov/cleancities/pdfs/ngvtf10_trans_lessons_learned.pdf

[69] Friedman, D. N., & Malcosky, N. D. 1995. Compressed Natural Gas Safety in Transit Operations: Clean Air Program http://144.171.11.39/view.aspx?id=573745

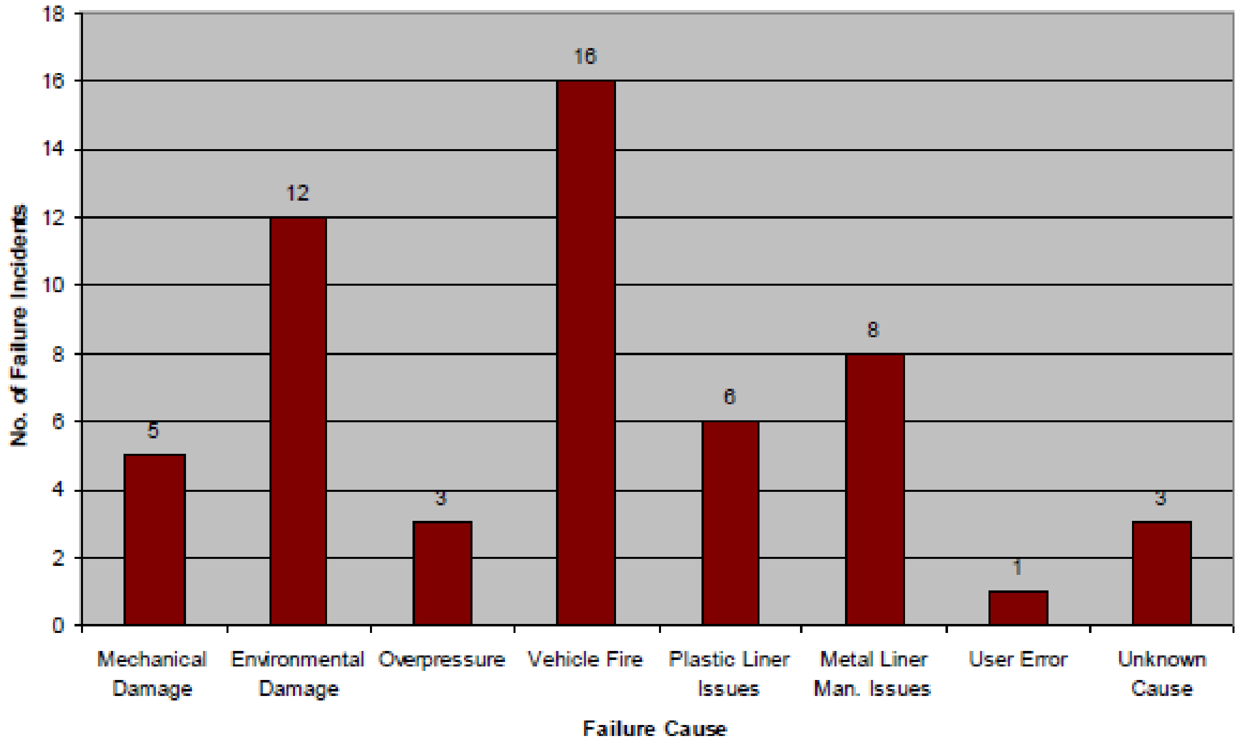

Figure 2-4: CNG Tank Failures Frequencies by Cause[70]

To date, there have been relatively few CNG cylinder failure incidents, including only two leading to fatalities[71,72] that have occurred on the approximately 115,000 CNG vehicles in the United States There were eight cylinder ruptures in the nine-year period between 1993 and 2001; about one rupture per 56,000 cylinder-years. Three of the eight CNG cylinder ruptures prior to 2002 were caused by glass fiber stress corrosion cracking due to battery acid exposure. Four other tanks ruptured due to severe physical tank damage, and one tank failed due to overpressurization. However, another CNG bus destroyed by an engine fire did not have CNG cylinders explode. In this case, their PRDs opened and released the gas, which was then ignited by the primary fire and produced a jet flame.[73] There have been similar cases of vehicle fires resulting in CNG cylinder PRD actuation and subsequent cylinder depressurization.[74] Other

[70] Wong, J. 2009. CNG & Hydrogen Tank Safety, R&D, and Testing www1.eere.energy.gov/hydrogenandfuelcells/pdfs/cng_h2_workshop_8_wong.pdf
[71] Clean Vehicle Education Foundation. 2010. How Safe are Natural Gas Vehicles? www.cleanvehicle.org/committee/technical/PDFs/Web-TC-TechBul2-Safety.pdf
[72] Clean Vehicle Education Foundation. 2012. Fatal accident removing cylinder solenoid valve www.cleanvehicle.org/technology/ValveFatality.pdf
[73] Gambone, L. 2005. CNG Cylinders 101 www.cleanvehicle.org/technology/CNGCylinderDesignandSafety.pdf
[74] Zalosh, R. 2009. CNG and Hydrogen Vehicle Fuel Tank Failure Incidents, Testing, and Preventive Measures www.mvfri.org/Contracts/Final%20Reports/CNGandH2VehicleFuelTankPaper.pdf

cylinder failures were attributable to a less catastrophic leakage event, including fewer than 50 Type 1 steel cylinder pinhole leaks and hundreds of Type 4 plastic liner leaks.[75]

The CNG safety incident reports provided by the Clean Vehicle Education Foundation and other cited sources show that in most cases incidents occur during or shortly after refueling, or in a CNG vehicle fire.[76]

CNG cylinder safety depends on a wide range of factors including:

- Handling procedures;
- Installation design and procedure;
- Operational and maintenance procedures;
- Inspection program and procedures and inspection personnel qualifications;
- Safety management systems for refueling facilities, vehicle workshops, and parking facilities; and
- Emergency response program and procedures.

For example, unauthorized drilling or grinding of cylinder surfaces has been reported in some CNG vehicle workshops. There are also reports of cylinder inspectors walking on roof-mounted composite cylinders on top of a CNG bus during in-situ inspection. Such unsafe work practices may indicate a gap in training for workshop staff and their supervisors, or gaps in the work procedures.[77]

The most recent CNG failure occurred as a result of human error when the owner attempted to remove a valve from a cylinder that had not been properly vented. [78] The cylinder exploded, killing the owner.[79]

A recent, non-fatal cylinder failure caused a delivery truck explosion in Los Angeles while employees of California Linen Services were refueling, causing serious injury.[80,81] In another incident, high outdoor temperature caused pressure to build up inside the fuel tank of a propane-powered truck, which activated the PRD. When the driver of the vehicle tried to stop the leaking

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[75] Wong, J. 2009. CNG & Hydrogen Tank Safety, R&D, and Testing www1.eere.energy.gov/hydrogenandfuelcells/pdfs/cng_h2_workshop_8_wong.pdf
[76] Hien Ly. 2011. Keeping Up the Good Safety Record of CNG Cylinders www.ngvglobal.com/keeping-up-the-good-safety-record-of-cng-cylinders-0803
[77] Ibid.
[78] Clean Vehicle Education Foundation. 2012. Fatal accident removing cylinder solenoid valve www.cleanvehicle.org/technology/ValveFatality.pdf
[79] News On 6. 2012. Broken Arrow Police: Business Owner Killed When CNG Tank Explodes www.newson6.com/story/17393515/broken-arrow-police-call-mans-death-accidential-death
[80] NHTSA. 2006. Class 8 Truck Tractor Braking Performance Improvement Study – Low Coefficient of Friction Performance and Stability Plus Parking Brake Evaluations of Four Foundation Brake Configurations www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/VRTC/ca/capubs/DOTHS809753.pdf
[81] CNG Chat. 2009. CNG Tank Failure in Los Angeles http://cngchat.com/forum/archive/index.php/t-4581.html

gas, static electricity caused gas ignition.[82] Both LPG and CNG cylinders have the potential for ignition near a venting PRD.

There have been reported complaints about fumes due to vented fuel inside a CNG vehicle. In Tulsa, Oklahoma, 140 public school buses that had used CNG since 1988 were checked following driver complaints. The school district considered installing carbon monoxide detectors in the buses[83] (although the reference noted that NGVs produce 70-90 percent less carbon monoxide in the exhaust than conventional vehicles).[84]

The literature indicates that some road and environmental conditions pose severe operating environments for pressure vessels: Vehicles may operate in temperature extremes that affect the mechanical properties of the cylinder. Multiple fills result in repetitive pressure changes that can lead to fatigue cracking over thousands of cycles. Exposure to road environments, including road salt, can lead to corrosion or abrasion, and there is vibration whenever the vehicle is in motion. Incidents such as vehicle fires and collisions can also thermally and/or mechanically damage CNG cylinders.

The NHTSA regulations that apply to CNG vehicles are FMVSS 301 (Fuel System Integrity), FMVSS 303 (Fuel System Integrity of Compressed Natural Gas Vehicles) and FMVSS 304 (CNG Fuel Container Integrity).[85] Of these regulations, only FMVSS 301 applies to MD/HDVs, while the other two are only applicable to light-duty vehicles. These regulations specify tests or installation requirements for CNG tanks and vehicles to account for each of these potential conditions.[86] Testing of CNG cylinders for in-service safety certification includes damage scenarios such as impact, abrasion, gunshot, and bonfire. Cylinders are designed not to rupture when fully fueled over six times a day, 365 days a year; far beyond what they will see in service. CNG cylinders (Types 1-4) are designed with a pressure safety factor of two, i.e., they should be able to contain a pressure up to twice the maximum fill pressure.[87] The cylinders are designed for a specific lifetime from 15 up to 25 years, and are required to be permanently labeled with the statement "*This container should be visually inspected after a motor vehicle accident or fire and at least every 36 months or 36,000 miles, whichever comes first, for damage and deterioration*." (FVMSS 304, § 571.304, S7.4 (g))[88]

[82] Morgenstern, M. 2012. Propane tank explodes in McDonald's drive-through www.theblaze.com/stories/propane-tank-explodes-in-mcdonalds-drive-through/

[83] Mills, R. 2011. TPS investigates claims that CNG-fueled buses made bus drivers sick; The district says it checked out all 140 CNG buses in its fleet www.krmg.com/news/news/local/tps-investigates-claims-cng-fueled-buses-made-bus-/nFhNq/

[84] Natural Gas Vehicles for America. 2012. NGVs and the Environment www.ngvc.org/about_ngv/ngv_environ.html

[85] NHTSA. 2009. FMVSS 304 CNG fuel container integrity www.nhtsa.gov/DOT/NHTSA/NVS/Crashworthiness/Alternative%20Energy%20Vehicle%20Systems%20Safety%20Research/811150.pdf

[86] Wong, J. 2009. CNG & Hydrogen Tank Safety, R&D, and Testing www1.eere.energy.gov/hydrogenandfuelcells/pdfs/cng_h2_workshop_8_wong.pdf

[87] Ibid.

[88] See FMVSS 304 and ANSI CSA NGV2 standard: "Periodic In-Service Inspection Requirements (Sec. 4.1.4, NGV2):"Each container shall be visually inspected at least every 36 months, or at the time of any re-installation, for external damage and deterioration…" CNG cylinder inspection guidelines are posted at

The Clean Vehicle Education Foundation (CVEF) sponsored by the DOE National Energy Technology Lab (NETL) developed a "CNG Fuel System Inspector Study Guide"[89] with industry stakeholders, which is required for certification of CNG fuel system and cylinder inspectors by CSA America. The CVEF also posted and maintains a comprehensive list of "Codes, Standards and Advisories Applicable to Natural Gas Vehicles and Infrastructure."[90] The literature indicates that aftermarket vehicle conversions to CNG, which are not within NHTSA's scope, represent over 50 percent of failure incidents, as shown in Figure 2-5.

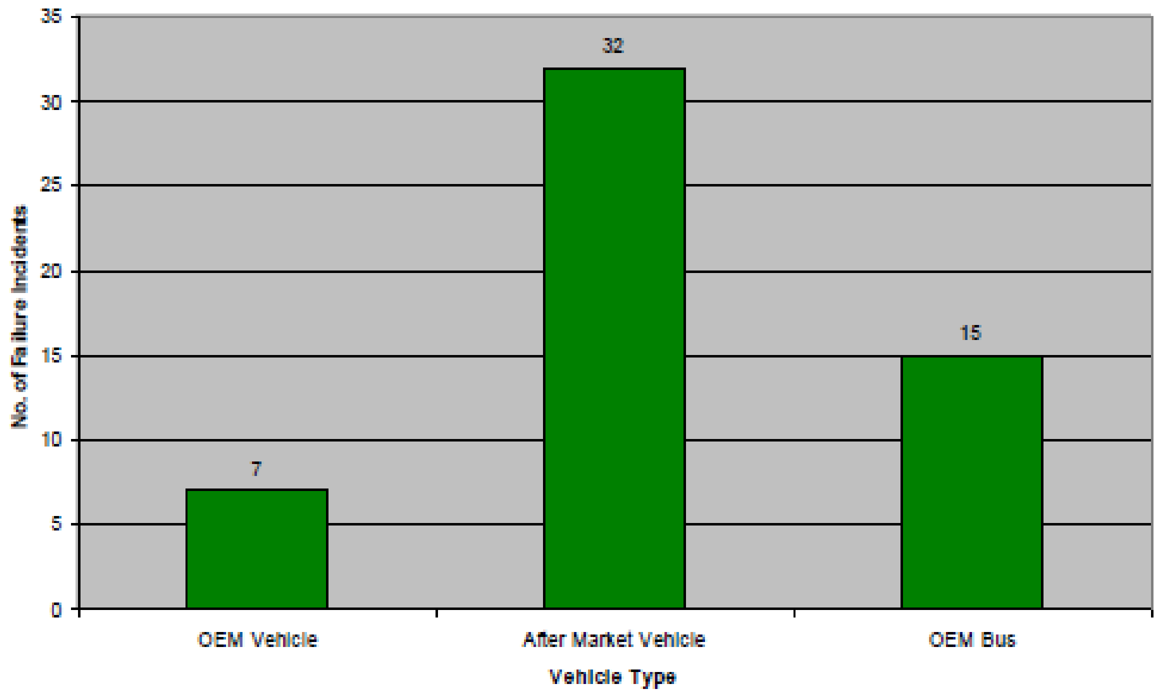

Figure 2-5: Prevalence of Aftermarket Conversions in CNG Failures[91]

2.2.1.4 Safety Considerations for LNG-Fueled Vehicles

From a material properties perspective, LNG poses different potential hazards than compressed natural gas (CNG). The energy density of LNG is greater than for CNG so more fuel can be stored onboard. This makes LNG well suited for Class 7 and 8 trucks that need a greater range.

Because it is a cryogenic liquid, spills of LNG can lead to a heavier-than-air vapor cloud that can travel horizontally from the spill site and then ignite some distance away.[92] In contrast, CNG is

www.transecoenergy.com/pages/CNG_Tank.htm; and www.cleanvehicle.org/committee/technical/PDFs/Web-TC-TechBul1-ContainerInspection.pdf

[89] See http://cleanvehicle.org/technology/Study_Guide_Final.pdf

[90] See Codes, Standards and Advisories Applicable to Natural Gas: www.cleanvehicle.org/technology/image/code.pdf

[91] Wong, J. 2009. CNG & Hydrogen Tank Safety, R&D, and Testing www1.eere.energy.gov/hydrogenandfuelcells/pdfs/cng_h2_workshop_8_wong.pdf

lighter than air, and rises and dissipates when leakage occurs. Because of LNG's extremely low temperature, odorants cannot be added, resulting in a potential increased hazard in the event of a leak, as workers cannot detect an odor.[93] There is a safety advantage of LNG over CNG: since the tanks are only pressurized to 150-230 psi, LNG systems are not exposed to the high-pressure explosion hazard of CNG systems.[94]

An LNG refueling station has a higher inventory of cryogenic fuel onsite, and therefore of stored energy, than a pipeline-fed CNG refueling station. Hazards relating to LNG include: fire, cryogenic burns, changes in properties of contacted materials (e.g., cryogenic embrittlement), and asphyxiation (by displacing oxygen). Ignition can result from contact with hot surfaces, open flames, and sparks, including static electricity.[95]

The low number of LNG vehicles currently in service in the United States means there is relatively little statistical safety data to draw on. Approximately 20-30 public safety incidents involving LNG vehicles have been reported since 1971 in the United States and Europe.[96] Almost all incidents were vehicle crashes. Fewer than half of the incidents resulted in a loss of cargo and only two of the incidents led to fires. Notably, there have been no fatalities reported from LNG vehicle crashes, and only the drivers of the LNG vehicles have been seriously injured. While the research literature indicate that the overall safety record of LNG trucks is good, in 2002 an LNG truck in Spain exploded in a boiling liquid, expanding-vapor type explosion.[97] Penetration of an LNG vehicle fuel tank below the liquid level could result in rapid ejection of LNG and formation of an ignitable vapor cloud. However, LNG tanks are designed to be more robust pressure vessels than conventional diesel fuel tanks, making a penetration of an LNG tank less likely than for a similarly mounted diesel-fuel tank. The National Petroleum Council cites several severe crashes or fires of LNG-powered trucks and buses in which the LNG tanks were not penetrated.[98] Some have suggested that the long-term durability of cryogenic fuel tanks still warrants further study.[99]

Venting from pressure relief devices on LNG vehicles parked for prolonged periods is expected as the liquefied gas evaporates. As a result, LNG vehicles must be stored outside or in facilities designed to collect and discharge methane vapor releases, so that gas releases cannot build up in enclosed spaces.

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[92] Whyatt, G. 2010. Issues Affecting Adoption of Natural Gas Fuel in Light- and Heavy-Duty Vehicles http://s3.amazonaws.com/zanran_storage/www.pnl.gov/ContentPages/184758856.pdf

[93] Friedman, D. M., & Malcosky, N. D. 1996. Liquefied Natural Gas Safety in Transit Operations: Final Report http://trid.trb.org/view.aspx?id=713273

[94] Westport HD. 2012. Servicing Heavy-Duty Natural Gas Trucks: Preparation And Shop Requirements www.automotiveworld.com/webinars/servicing-heavy-duty-natural-gas-trucks-preparation-and-shop-requirements/

[95] Friedman, D. M., & Malcosky, N. D. 1996. Liquefied Natural Gas Safety in Transit Operations: Final Report http://trid.trb.org/view.aspx?id=713273

[96] National Petroleum Council. 2012. An Initial Qualitative Discussion on Safety Considerations for LNG Use in Transportation www.npc.org/FTF_Topic_papers/19LNG_Transportation.pdf

[97] Ibid.

[98] Ibid.

[99] Oil and Gas Journal. 2012. LNG seen viable fuel for heavy-duty trucks www.ogj.com/articles/2012/06/lng-seen-viable-fuel-for-heavy-duty-trucks.html

A methane explosion occurred inside an LNG-powered 60-foot articulated bus during servicing in 1992. The bus had just been delivered and was being readied for LNG operation. Although such repairs are supposed to be performed outdoors, because of inclement weather, the mechanic performed the work in a conventional bus bay. After a gas detector alarm went off, the mechanic overrode it and started the bus engine to move it outside; this ignited the flammable natural gas-air mixture inside the bus and blew out all of the windows and roof hatches. [100]

Waste Management, Inc. provided a positive case study with its fleet of heavy-duty refuse trucks powered by LNG that have been based at a Pennsylvania facility since 1997.[101] This implementation was considered successful by both Mack Truck and Waste Management, with no safety incidents reported. Drivers and refuse workers reported that there was no difference in operation between the propulsion systems. The refuse workers preferred the LNG trucks because of their lack of diesel odor and quieter operation. The LNG fuel station was installed with the storage tank underground and was reported to operate well, except for minor problems with the fuel nozzle. Waste Management deployed approximately 200 LNG refuse collection trucks in locations throughout California based on the outcome of the pilot fleet.

Safety in the design and operation of the LNG refueling infrastructure is partly addressed by National Fire Protection Association (NFPA) Code 57, which requires a drainage containment system to catch any liquid draining from the LNG tank and establishes a minimum distance between the edge of the drainage system and any buildings or property lines. The NFPA codes and standards are voluntary. Regulatory bodies such as the Federal Energy Regulatory Commission (FERC) may mandate compliance with NFPA standards in safety reviews of LNG facilities.

Recent efforts, such the Shell collaboration with Mack and Volvo to develop LNG-fueled trucks, and the expansion of the LNG Flying J network of LNG refueling stations at truck stops in the Great Lakes and Gulf Coast regions[102] may lead to broader adoption of LNG. An indirect safety impact of LNG-fueled MD/HDVs could also be an increase in the number of tanker trucks transporting LNG to many more refueling stations. This would increase the potential for road incidents involving LNG tanker trucks. However, if fueling stations were to perform their own liquefaction, the current natural gas pipeline distribution system could be used instead of tanker trucks. This would reduce the existing hazards from hauling diesel and gasoline fuel on roads and highways.[103]

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[100] Foss, M. M. 2006. LNG Safety and Security www.beg.utexas.edu/energyecon/lng/documents/CEE_LNG_Safety_and_Security.pdf

[101] Clark, K., Paul, N.. Clark, N. 2001. Waste Management's LNG Truck Fleet Final Results www.afdc.energy.gov/pdfs/waste_lng_final.pdf

[102] See http://breakingenergy.com/2013/04/23/natural-gas-in-transport-tomorrow-s-fuel-today/

[103] National Petroleum Council. 2012. An Initial Qualitative Discussion on Safety Considerations for LNG Use in Transportation at www.npc.org/FTF_Topic_papers/21-LNG_in_Transportation.pdf

2.2.1.5 Findings and Conclusions

This literature review did not produce any clear safety contraindications to the use of CNG or LNG fueled vehicles. It did however, identify some educational and operating procedure gaps and the potential regulatory opportunity to refine fuel system and maintenance facility standards. Robust training for people who handle natural gas, as well as the sound design and manufacture of natural gas storage tanks, may reduce the potential for leaks, tank ruptures, fires, and explosions.

Both CNG- and LNG-powered vehicles present hazards distinct from those of diesel vehicles, and call for distinct engineering and process controls to assure safe operability. However, based on the reported incident rates of NGVs and the experiences of adopting fleets, it appears that NGVs can be operated at least as safely as diesel MD/HDVs. Using natural gas instead of diesel fuel helps fleets comply with the MD/HD greenhouse gas rules that require up to 20 percent emissions reduction by 2018.

There are currently no generally accepted codes and building standards for facilities that house CNG/LNG vehicles but which do not include a fueling facility; thus, facility safety is handled at the local level by fire marshals.[104,105] Natural gas is lighter than air, so ventilation rates near the ceiling should be high enough to disperse the gas well before it reaches the lower flammability limit. Since LNG vapor initially stays low in case of a leak, it is recommended that enclosed LNG vehicle facilities install only classified (explosion-proof) electrical wiring and equipment in all maintenance facility work areas, both at low elevations and near the ceiling. It is possible to reduce such potential hazards by eliminating potential ignition sources within the facility.[106] In addition, combustible gas detection and alarm systems could be installed.[107]

Essentially the same safety procedural requirements applicable to CNG fleets are relevant to LNG maintenance facilities, with one significant difference. Since LNG vehicles are expected to normally vent natural gas from LNG tank PRVs, all maintenance and storage locations should be equipped with a device to connect to PRV outlet and vent escaping gas at the building roof level. Alternatively, LNG vehicles should be de-fueled before entering the facility. This is not necessary for CNG vehicles, which are not expected to vent gas from their PRDs except in the event of vehicle fire or equipment failure. Unlike for CNG vehicles, there is limited data on modifying maintenance facilities to accommodate LNG vehicles, and further facility standards development and their enforcement are warranted. Although the NHTSA regulatory mission does not cover the safety of and vehicle fueling interfaces, they impact both vehicle highway safety, and the adoption of alternative-fuel vehicles.

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[104] Reich, S. L., & Kolpakov, A. 2011. Tracking Costs of Alternatively Fueled Buses in Florida www.nctr.usf.edu/2011/12/tracking-costs-of-alternatively-fueled-buses-in-florida-2/

[105] Westport HD. 2012. Servicing Heavy-Duty Natural Gas Trucks: Preparation And Shop Requirements https://s3.amazonaws.com/automotiveworld/presentations/12-19-12-Servicing+Heavy-Duty-Natural-Gas-Trucks.pdf

[106] NHTSA. 2010a. Study of Heavy Truck S-Cam, Enhanced S-Cam, and Air Disc Brake Models Using NADS www.nhtsa.gov/DOT/NHTSA/NVS/Vehicle%20Research%20&%20Test%20Center%20(VRTC)/ca/capubs/811314.pdf

[107] Adams, R. 2010a. CNG Transit Experience Survey www1.eere.energy.gov/cleancities/pdfs/ngvtf10_trans_lessons_learned.pdf

The literature indicates that a number of preventive and safe handling procedures would ensure the safety of vehicles, personnel, and facilities. These include:

- Equipping LNG storage vessels with redundant pressure release valves to prevent an unsafe buildup of pressure when the LNG warms over time and changes to a gaseous state.
- Emptying the LNG tanks or reclaiming the venting gas if a vehicle is parked for prolonged periods. [108] During defueling of the LNG vehicle, 30 percent of the fuel is typically lost in transfer; thus defueling could only occur outdoors or in a properly ventilated indoor facility.[109] Chemical exposure of CNG cylinders could be avoided through proper containment or isolation, e.g., from road salt exposure or battery acid.[110]
- Proper insulation, orientation and ventilation of hot components are also critical to safety.[111]
- Electric accessory systems are recommended on board NGVs to reduce the risk of a vehicle fire.[112] CNG cylinders should be anchored at all times to prevent rocketing should a rupture occur.[113] Fleets with vehicles that have rooftop CNG cylinders could develop and follow Standard Operating Procedures (SOP) to avoid collisions with low garage doors, overpasses, etc.
- The literature indicates that best practices for proactive maintenance and inspection and for driver training would help prevent hose fires or brake fires that could lead to a CNG/LNG fuel tank venting.
- Personnel safety training such as strict enforcement of "no smoking" policies, the use of non-sparking tools, and the use of personal protective equipment would also reduce operational CNG/LNG hazards.[114]

Some revisions to fuel tank fire exposure testing and to tank thermal protection and inspection to prevent future incidents are recommended in the literature. One source specifically recommends expanding the cylinder certification test-to-test survivability against a fire localized away from the PRD, instead of against a bonfire that equally heats the cylinder and the PRD.[115]

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[108] National Petroleum Council. 2012. An Initial Qualitative Discussion on Safety Considerations for LNG Use in Transportation www.npc.org/FTF_Topic_papers/21-LNG_in_Transportation.pdf

[109] Westport HD. 2012. Servicing Heavy-Duty Natural Gas Trucks: Preparation And Shop Requirements https://s3.amazonaws.com/automotiveworld/presentations/12-19-12-Servicing+Heavy-Duty-Natural-Gas-Trucks.pdf

[110] Lapetz, J. 2009. Safety Warning: Acid Exposure of Vehicular CNG Cylinders www.ngvglobal.com/safety-warning-acid-exposure-of-vehicular-cng-cylinders-0911

[111] Adams, R. 2010a. CNG Transit Experience Survey www1.eere.energy.gov/cleancities/pdfs/ngvtf10_trans_lessons_learned.pdf

[112] Ibid.

[113] NHTSA. 2010a. Study of Heavy Truck S-Cam, Enhanced S-Cam, and Air Disc Brake Models Using NADS www.nhtsa.gov/DOT/NHTSA/NVS/Vehicle%20Research%20&%20Test%20Center%20(VRTC)/ca/capubs/811314.pdf

[114] Ibid.

[115] Wong, J. 2009. CNG & Hydrogen Tank Safety, R&D, and Testing www1.eere.energy.gov/hydrogenandfuelcells/pdfs/cng_h2_workshop_8_wong.pdf

2.2.2 Biodiesel

Biodiesel is a domestically produced renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant grease. Biodiesel consists of fatty acid alkyl esters, fatty acid methyl esters, or long-chain mono alkyl esters. Like petroleum diesel, biodiesel is used to fuel compression-ignition engines, which run on petroleum diesel, but it is cleaner burning. Biodiesel can be blended and used in different concentrations, including B100 (pure biodiesel), B20 (20 percent biodiesel, 80 percent petroleum diesel), B5 (5% biodiesel, 95% petroleum diesel) and B2 (2% biodiesel, 98% petroleum diesel). B20 is the most common biodiesel blend in the United States.

The EPA highlights the benefits and disadvantages of using biofuel blends. Disadvantages include: concerns about B100's adverse impact on engine durability and unsuitability for use at low temperature due to increase in viscosity; lower fuel economy and power (10% lower for B100, 2% for B20); current higher costs; and a possible increase in nitrogen oxide emissions.

2.2.2.1 Penetration/Adoption

Between 2001 and 2011, domestic biodiesel production has increased from virtually zero to approximately one billion gallons per year (Figure 2-6). With the recent addition of Mack and Volvo Trucks, more than 65 percent of diesel vehicle manufacturers in the U.S. market now support B20 or higher biodiesel blends. Volvo and Mack are among the first OEMs to extend B20 approval both to their new 2010 EPA emissions certified engines as well as to their older legacy models.[116] Moreover, the first hybrid-electric trucks to support the use of B20 biodiesel blends were recently introduced, further expanding the potential for biodiesel adoption.[117] Blends up to B20 can be used in existing equipment without modification. In September 2011, Alliant began to use soybean-based fuel with B5 in 126 utility trucks. The vehicles using the blended fuel are International straight trucks, including trenchers, digger derricks, tractors, and bucket trucks.[118]

According to the latest APTA survey, at least 40 public transit agencies in North America operate buses running on biofuels.[119] The San Francisco Municipal Transportation Agency (SFMTA) has the largest municipal biodiesel fleet in the United States with 512 vehicles using B20 – including both biodiesel and biodiesel-hybrid buses. In 2011, biodiesel fueled about 8 percent of U.S. buses.[120] In 2011, biodiesel fueled about 8 percent of urban transit buses.

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[116] Biodiesel Magazine. 2012. Mack and Volvo Trucks join growing list of B20 supporters www.biodieselmagazine.com/articles/8470/mack-and-volvo-trucks-join-growing-list-of-b20-supporters

[117] Construction Business Owners. 2012. Hino Trucks Honored at Biodiesel Conference www.constructionbusinessowner.com/topics/hino-trucks-honored-biodiesel-conference

[118] Bennett, S. 2008. Alliant Switches Fleet Vehicles to Biofuels www.worktruckonline.com/Channel/Fuel-Management/Article/Story/2008/07/Alliant-Switches-Fleet-Vehicles-to-Biofuels.aspx?prestitial=1

[119] See APTA 2012 "Transit on the cutting edge of clean technologies" at www.apta.com/resources/statistics/Documents/Transit-Clean-Technology.pdf

[120] Gentry, W. 2012. Statement of William Gentry, President, Gentry Trailways and on behalf of American Bus Association and United Motorcoach Association Subcommittee on Highways and Transit, House Transportation and infrastructure Committee, U.S. House of Representatives www.gpo.gov/fdsys/pkg/CHRG-112hhrg75852/html/CHRG-112hhrg75852.htm

Biodiesel vehicles accounted for about 7 percent of the new buses and more than 14 percent of the new demand.

2.2.2.2 Benefits

Although biodiesel contains about 8 percent less energy per gallon than petroleum diesel, corresponding to a 1- 2 percent decrease in energy density and a commensurate FE penalty, engines operating on B20 blends have similar fuel consumption, horsepower, and torque to engines running on petroleum diesel. Most B20 users reported no noticeable difference in performance or fuel economy, according to the DOE/AFDC sources cited. B20 has a higher cetane number (a measure of the ignition value of diesel fuel) and higher lubricity (the ability to lubricate fuel pumps and fuel injectors) than petroleum diesel.[121] B20 and lower-level blends generally do not require engine modifications.

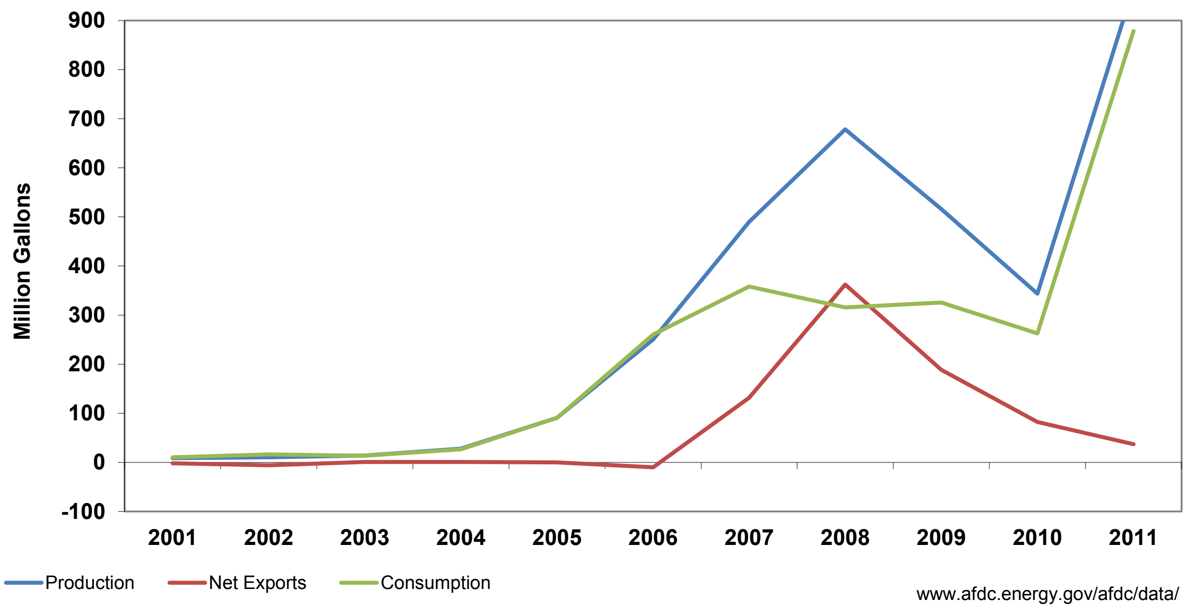

Figure 2-6: U.S. Biodiesel Production and Consumption[122]

Compared with using petroleum diesel, using biodiesel reduces tailpipe emissions of unburned hydrocarbons (HC), carbon monoxide (CO), sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter (PM). The reductions increase as the amount of biodiesel blended into diesel fuel increases. B20 has been shown to reduce PM emissions 10 percent, CO 11 percent, unburned HC 21 percent, and carbon dioxide emissions by 15 percent. [123] In addition, retrofit diesel oxidation catalysts (DOCs) and diesel particulate filters (DPFs) can operate effectively on vehicles using a biodiesel blend fuel up to B20 provided that

[121] DOE Alternative Fuels Data Center. 2012. Biodiesel Blends www.afdc.energy.gov/fuels/biodiesel_blends.html
[122] DOE EERE. 2012a. Alternative Fuels and Advanced Vehicles Data Center Natural Gas at www.afdc.energy.gov/fuels/natural_gas.html
[123] DOE Alternative Fuels Data Center. 2012. Biodiesel Blends www.afdc.energy.gov/fuels/biodiesel_blends.html

this biodiesel blend conforms to appropriate biodiesel specifications, e.g., ASTM Standard D7467.[124]

2.2.2.3 Safety Considerations

In contrast with petroleum diesel, biodiesel is nontoxic and contains no hazardous materials.[125] It causes less damage than petroleum diesel if spilled or released in the environment and it is less combustible. The flashpoint for biodiesel is higher than 150°C, compared to 52°C for petroleum diesel. Biodiesel is also safe to handle, store, and transport.[126] When conditions do not permit biodiesel-fueled vehicles to return to their base, they can be refueled with conventional diesel. Since biodiesel vehicles are essentially bi-fueled, there is no increased risk of vehicle stranding.[127]

Operational safety concerns include:

- Higher biodiesel blends have a solvent effect that can clean a vehicle's fuel system and release sludge deposits accumulated from previous petroleum diesel use. The release of these deposits may initially clog filters.
- Biodiesel blends can gel at temperatures below 20 degrees Fahrenheit if the manufacturing process leaves too much glycerin in the fuel.[128]
- Since biodiesel is a rich food source, microbial filter-clogging may occur over time.

To combat potential biofouling accumulation, use of a moisture dispersant and biocide may be necessary.[129] The literature provides best practices for biodiesel storage, such as topping off tanks to prevent condensation and keeping the tank temperature at least 10° F above the cloud point of the blended fuel.

There are a number of material compatibility issues associated with B100 that could affect vehicles with engines built before 1994:

- B100 can swell or degrade hoses, gaskets, seals elastomers, glues, and plastics with prolonged exposure.[130] Natural or nitrile rubber compounds, polypropylene, polyvinyl, and Tygon materials are particularly vulnerable. Fuel pumps contain rubber valves that may fail.
- Extensive contact with copper, brass, bronze, lead, tin or galvanized surfaces may also accelerate fuel oxidation.

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[124] Manufacturers of Emission Controls Association (MECA). 2012. What is Retrofit? at www.meca.org/diesel-retrofit/what-is-retrofit
[125] National Biodiesel Board. 2009b. Biodiesel sample material safety data sheet www.biodiesel.org/extpages/search-results?q=msds
[126] DOE Alternative Fuels Data Center. 2012. Biodiesel Blends www.afdc.energy.gov/fuels/biodiesel_blends.html
[127] Bennett, S. 2008. Alliant Switches Fleet Vehicles to Biofuels www.worktruckonline.com/Channel/Fuel-Management/Article/Story/2008/07/Alliant-Switches-Fleet-Vehicles-to-Biofuels.aspx?prestitial=1
[128] DOE Alternative Fuels Data Center. 2012. Biodiesel Blends www.afdc.energy.gov/fuels/biodiesel_blends.html
[129] DOE Biodiesel Handling and Use Guide. 2009. www.nrel.gov/vehiclesandfuels/pdfs/43672.pdf
[130] Ibid.

However, most engines made after 1994 have been constructed with gaskets and seals that are generally biodiesel resistant.[131] The National Biodiesel Board recommends a regular maintenance and leak inspection schedule for the fuel lines and components of biodiesel MD/HDVs for newer vehicles; this is critical for older vehicles.

2.2.2.4 Findings and Conclusions

Biodiesel is a drop-in alternative fuel that can support MD/HDV progress toward GHG and criteria pollutant reductions without major capital investment or infrastructure barriers. There is a minor decrease in fuel efficiency due to the 8 percent lower energy density of biodiesel versus petroleum diesel, but the magnitude of the emissions decrease is substantially larger.

As for any bi-fueled vehicles, the potential for refueling with petroleum diesel reduces potential safety risks associated with vehicle stranding due to fuel supply shortage or refueling infrastructure limitations.

In conclusion, the literature reviewed and DOE/AFDC resources[132]indicate that biodiesel, as a viable drop-in alternative fuel, has both safety and environmental benefits.

2.2.3 Liquefied Petroleum Gas (Propane)

Propane, also known as liquefied petroleum gas (LPG) or autogas, has been used worldwide as a vehicle fuel for decades. It is stored as a liquid, and has a propane fueling infrastructure that is widespread. Propane is a three-carbon alkane gas (C_3H_8). Stored under pressure inside a tank, propane turns into a colorless, odorless liquid. As pressure is released, the liquid propane vaporizes and turns into gas that is used for combustion. Propane is a non-toxic, non-carcinogenic, and non-corrosive fuel. It is insoluble in water and does not impact groundwater, surface water, or soil.[133] An odorant, ethyl mercaptan, is added for leak detection.[134]

Propane has a high octane rating and excellent properties for spark-ignited internal combustion engines. There is interest in propane as an alternative transportation fuel because of its domestic availability, potentially cleaner-burning qualities, and relatively low cost. It is the world's third most common engine fuel and is considered an alternative fuel under the Energy Policy Act of 1992.[135]

When sold as vehicle fuel, propane can be a mixture of propane with smaller amounts of other gases. According to the Gas Processors Association's HD-5 specification for propane, it must consist of 90 percent propane, no more than 5 percent propylene, and 5 percent other gases, primarily butane and butylene. [136] To compare fuel efficiency on a gallon-to-gallon basis, the

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[131] National Biodiesel Board. 2009a. B100 Material Compatibility www.biodiesel.org/docs/ffs-performace_usage/materials-compatibility.pdf?sfvrsn=4

[132] See www.afdc.energy.gov/fuels/biodiesel_benefits.html

[133] Bertram, M. R, Burham,. A. Bertram. K. 2010. Propane Vehicles: Status, Challenges, and Opportunities www1.eere.energy.gov/cleancities/pdfs/propanepaper09_final.pdf

[134] DOE Alternative Fuels Data Center. 2013b. Propane www.afdc.energy.gov/fuels/propane.html

[135] Ibid.

[136] Ibid.

energy content of propane is 66 percent that of diesel, thus requiring more propane fuel to travel an equivalent distance even in an optimized engine.[137] Larger storage tanks can increase range, but the additional weight displaces payload capacity and can slightly increase the consumption of fuel.

Propane is stored and handled as a liquid at the fuel dispenser. New nozzles and valves have been introduced that meet vapor control standards and prevent volatile organic compound (VOC) emissions from escaping from refueling stations. Onboard a vehicle, propane is stored at about 150 pounds per square inch—about twice the pressure of an inflated truck tire. Under this pressure, propane becomes a liquid with an energy density 270 times greater than the gaseous form.[138] To operate a vehicle on propane as either a dedicated fuel or bi-fuel (i.e., switching between gasoline and propane) vehicle, only a few modifications must be made to a gasoline engine. Propane cannot be used in a diesel engine without major modifications since a spark or diesel-pilot ignition system would be required. The propane tank is typically located under the body of the vehicle.

2.2.3.1 Penetration/Adoption

According to the Propane Education and Research Council, there are more than 270,000 on-road propane vehicles in the United States. Many are used in fleet applications, such as police cars, shuttles, street sweepers, and school buses.[139] As shown in Table 2-1, the Energy Information Administration estimates approximately 64,000 propane MD/HDVs operate in the United States[140] The World LP Gas Association reports more than 13 million propane-fueled vehicles in operation worldwide.[141] Propane vehicles can either be conversions from gasoline/diesel vehicles or purchased from OEMs. There are about 2,600 propane refuelers in the United States, mostly in California and the southern United States, particularly Texas.[142]

[137] Bertram, M. R. W. A. B. K. 2010. Propane Vehicles: Status, Challenges, and Opportunities www1.eere.energy.gov/cleancities/pdfs/propanepaper09_final.pdf
[138] DOE Alternative Fuels Data Center. 2013b. Propane www.afdc.energy.gov/fuels/propane.html
[139] Propane Education and Research Council. 2013. Propane Exceptional Energy http://autogasusa.org/
[140] Energy Information Administration. 2010. How many alternative fuel and hybrid vehicles are there in the U.S.? www.eia.gov/tools/faqs/faq.cfm?id=93&t=4
[141] Bertram, M. R. W. A. B. K. 2010. Propane Vehicles: Status, Challenges, and Opportunities www1.eere.energy.gov/cleancities/pdfs/propanepaper09_final.pdf
[142] Motavalli, J. 2012. Making the case for propane: from gas grills to cars and trucks www.cartalk.com/content/making-case-propane-gas-grills-cars-and-trucks

Table 2-1: Alternative Fuel Vehicles in Use in the United States by Fleet Operators: 2010[143]

	Medium Duty	Heavy Duty
Natural Gas — Total	**22,575**	**28,976**
Compressed Natural Gas	22,521	26,000
Liquefied Natural Gas	54	2,976
LPG — Propane	27,771	36,057

School buses fueled by propane are available from several school bus manufacturers, including Blue Bird Corporation and Collins Bus Corporation.[144] In 2012, CleanFUEL U.S.A and Collins Bus Corporation announced the delivery of 134 propane school buses to First Student, Inc. for serving the Seattle Public Schools and Portland Public Schools.[145] In 2009, there were approximately 2,000 LPG school buses out of a nationwide fleet of about 480,000. Blue Bird plans to sell another 14,200 buses by 2013. Propane has also found significant adoption in the paratransit bus market. In 2006, according to the American Public Transportation Association, 3.7 million gallons of LPG were consumed by paratransit buses. [146]

In addition to commercially available single and bi-fuel propane MD/HDVs, a propane-electric hybrid transit bus is also manufactured by E-bus.[147]

2.2.3.2 Benefits

Propane fuel costs significantly less than diesel fuel. MD/HDVs fueled by propane have the same horsepower, torque, and towing capacity of diesel-fueled vehicles.[148] Lower maintenance costs are another reason for propane use in high-mileage vehicles. Its high octane and low carbon and oil contamination characteristics have resulted in greater engine life than conventional engines. Because the fuel mixture of propane and air is completely gaseous, cold start problems associated with liquid fuel are reduced.

Since propane requires relatively low compression, a pump of only a few horsepower can be sufficient. A home propane refueler can be purchased for approximately $1,500.[149]

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143 Energy Information Administration. 2010. How many alternative fuel and hybrid vehicles are there in the U.S.? www.eia.gov/tools/faqs/faq.cfm?id=93&t=4

144 Propane Education and Research Council. 2013. Propane Exceptional Energy http://autogasusa.org/

145 Business Wire. 2012. CleanFUEL USA and Collins Bus Corporation Deliver More than 100 Propane Autogas-Powered Buses www.businesswire.com/news/home/20121114005626/en/CleanFUEL-USA-Collins-Bus-Corporation-Deliver-100

146 Bertram, M. R. W. A. B. K. 2010. Propane Vehicles: Status, Challenges, and Opportunities www1.eere.energy.gov/cleancities/pdfs/propanepaper09_final.pdf

147 Ibid.

148 Propane Education and Research Council. 2013. Propane Exceptional Energy http://autogasusa.org/

149 Motavalli, J. 2012. Making the case for propane: from gas grills to cars and trucks www.cartalk.com/content/making-case-propane-gas-grills-cars-and-trucks

Compared with vehicles fueled by conventional diesel and gasoline, propane vehicles can produce lower amounts of some harmful air pollutants and greenhouse gases, depending on vehicle type, drive cycle, and engine calibration.[150]

2.2.3.3 Safety Considerations

Similar to natural gas, there are two potential failure scenarios for propane: overpressure due to tank overfill, and unintended ignition (due to leaks or crash).

In the first scenario, to prevent overpressure, most propane vehicles have a bleed, or splitter valve attached to the tank. During refueling the valve is opened, releasing vapor from the fuel tank and making room for the liquid propane to enter the tank.[151] Once the tank is filled with 80 percent liquid, additional propane will cause the valve to vent liquid fuel. This Overfill Prevention Device (OPD) supplements the automatic stop-fill system on the fueling station side. There are both safety and emissions implications of overfilled fuel tanks, so a pressure release device (PRD) is provided to release propane gas if pressure rises in the tank beyond safe levels.[152]

The DOE Clean Cities program conducted tests on 105 propane vehicles across seven fleets during fueling. Results showed that the OPDs on nearly 16 percent of the tanks failed to stop fueling at the necessary level.[153] While the 16 percent OPD failure rate is potentially significant, tanks are also equipped with pressure relief devices specifically to ensure safe pressure levels.

If a tank is overfilled during a cool time of day and sits without being used, warmer temperatures later in the day will expand the fuel, which could lead to a fuel release or leak through the pressure relief device.[154] Indeed, overfill is one of three necessary conditions for a potentially hazardous ignition incident to occur: 1) overfilling leaves inadequate room in the tank for expansion; 2) rising ambient temperatures then cause fuel expansion and release; and 3) an ignition source is present.

The physical properties of propane that are relevant to fire and explosion hazard in the event of a leak are different from the properties of natural gas. Propane, unlike natural gas, is heavier than air. Vapors therefore tend to fall to the ground level and can collect to a flammable level in low areas such as service pits. In contrast to natural gas, which dissipates as it rises, the dissipation of propane vapors is primarily based on air movement, and it will dissipate to non-hazardous concentrations faster in windy conditions than in still conditions.

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[150] DOE Alternative Fuels Data Center. 2013b. Propane www.afdc.energy.gov/fuels/propane.html
[151] Bertram, M. R. W. A. B. K. 2010. Propane Vehicles: Status, Challenges, and Opportunities www1.eere.energy.gov/cleancities/pdfs/propanepaper09_final.pdf
[152] DOE Alternative Fuels Data Center. 2010. Propane Tank Overfill Safety Advisory www.afdc.energy.gov/technology_bulletin_1008.html
[153] Ibid.
[154] Bertram, M. R. W. A. B. K. 2010. Propane Vehicles: Status, Challenges, and Opportunities www1.eere.energy.gov/cleancities/pdfs/propanepaper09_final.pdf

Safety training manuals for propane-fueled vehicles include appropriate emergency responses to crash-related propane tank truck fire scenarios .[155]

2.2.3.4 Conclusions and Recommendations

LPG or propane fueled vehicles can be as operationally safe as the conventionally-fueled MD/HDVs. The pressurization of the tanks is relatively low, and there are overfill protection measures on both the fuel station and on board tank sides. Although tank OPDs have been found to have a failure rate of about 16 percent, excess pressure in the tank resulting from overfill is bled out through a PRD. Similarly, if the pressure in the tank increases due to ambient temperature after it is filled, the PRD is designed to protect against overpressurization. Thus, both the OPD and the PRD would have to fail for a tank to rupture due to overpressurization. No such documented incident could be found in the literature and on the Internet. However, it is critical to eliminate any ignition sources near a propane tank PRD.

Best practices for fleets in the literature include ongoing inspections of the OPDs, training and educating propane vehicle users about preventing overfill, and having procedures to respond safely to a venting PRD. Safety standards for maintenance, inspection, and emergency response training have been promoted by industry groups, such as the National Propane Gas Association Technology Standards and Safety Committee, the Propane Education and Research Council (PERC), and the Underwriters Laboratory.[156] The Propane Education and Research Council posts resources on codes, regulations and best practices for the safe operation of propane fueled fleets.[157]

There are also safety guidelines to be considered when developing propane-refueling infrastructure for MD/HDVs. This includes the National Fire Prevention Association's NFPA 58 Vehicular Liquefied Petroleum Gas Code, which applies to the design and installation requirements of propane refueling facilities.[158] Local fire marshals typically ensure compliance with this code. In addition, propane suppliers can provide guidance to MD/HDVs owners and operators on the appropriate amount of propane to be stored on site to adequately meet vehicle fueling needs.[159]

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[155] See "Tactical response guidelines for propane emergencies: Scenario #8
Propane Fueled Delivery Truck Fire" at
www.propanesafety.com/uploadedFiles/Safety/Workforce_Training_programs/Propane_Emergencies_(PE)_Program/Energencies_PDFs/Scenario%208.pdf

[156] Bertram, M. R. W. A. B. K. 2010. Propane Vehicles: Status, Challenges, and Opportunities www1.eere.energy.gov/cleancities/pdfs/propanepaper09_final.pdf; and 2007 Propane Education & Research Council, Eight Step Incident Management Process©, Michael Hildebrand and Gregory Noll at www.propanesafety.com/uploadedFiles/Safety/Workforce_Training_programs/Propane_Emergencies_(PE)_Program/REVISED_PE3_Text.pdf

[157] See postings at www.propanesafety.com/

[158] National Fire Protection Association. 2011. NFPA 58: Liquiefied petroleum gas code www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=58&cookie_test=1

[159] DOE Alternative Fuels Data Center. 2013b. Propane www.afdc.energy.gov/fuels/propane.html

2.3 *Drivetrain Hybridization and Electrification*

There are two main types of hybrid technologies that can be used in medium- and heavy-duty vehicles:

- *Hybrid electric vehicles* (HEV) use an electric motor and generator, an energy storage system and power electronics, and an internal combustion engine. Hybrid electric vehicles are available across all weight classes in medium and heavy-duty vehicles.

- *Hydraulic hybrid vehicles* (HHV) use pressurized hydraulic fluid instead of electric charge as an additional energy storage system and as a power source, to complement the internal combustion engine. Due to its relatively high power density, but low energy capacity limited by accumulator size, the hydraulic system is eminently suitable for vehicles such as refuse trucks, transit buses, and delivery vehicles that operate in stop-and-go traffic.

HEV and EV adoption broken out by technology type includes:

- Series Hybrid
    - ***Electric.*** 3,800 transit buses with the BAE series drivetrain are in service globally[160], including 1,675 in New York City (28% of the bus fleet).[161]
    - ***Hydraulic.*** 11 Autocar E3 refuse trucks are in use by City of Miami with Parker RunWise drivetrain. UPS, Purolator, and FedEx are operating 48 Freightliner HH series trucks. Autocar E3 refuse trucks are also operating in NC, IN, TX, and CA.

- Parallel Hybrid
    - ***Electric.*** 6,000 Eaton hybrid drivetrains are in service worldwide (2,500 electric buses in Asia, 300 electrics in Europe, and 3,200 in North America). Coca-Cola has operated 142 hybrid box trucks (33,000 lb.) in North American cities since 2008, and larger parallel hybrid drive trucks (55,000 lb.) for its bulk-delivery applications since 2009.[162]
    - ***Hydraulic.*** 100 Eaton "Hydraulic Launch Assist" drivetrains are in service on Peterbilt refuse trucks.

- Electric
    - At least 20 fleets are using Smith or other electric MD box trucks. Frito-Lay Foods is the leading adopter (275 electric trucks), followed by AT&T, Staples, Coca-Cola, Pacific Gas & Electric, and Kansas City Power & Light. In addition, the Santa Barbara Metropolitan Transit District has operated 20 22-foot electric

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[160] BAE Systems. 2012. The Heavy-Duty Hybrid www.hybridrive.com/

[161] Gentry, W. 2012. Statement of William Gentry, President, Gentry Trailways and on behalf of American Bus Association and United Motorcoach Association Subcommittee on Highways and Transit, House Transportation and infrastructure Committee, U.S. House of Representatives www.gpo.gov/fdsys/pkg/CHRG-112hhrg75852/html/CHRG-112hhrg75852.htm

[162] DOE EERE. 2011. Project Startup: Evaluating Coca-Cola's Class 8 Hybrid-Electric Delivery Trucks www.nrel.gov/docs/fy11osti/49621.pdf

buses for over two decades. In addition to Smith, at least 4 other manufacturers offer MD/HDV battery electric trucks for commercial sale in the United States:

- Electric Vehicles International,
- AMP Electric Vehicles,
- Boulder Electric Vehicles, and
- Motiv Power Systems.

The fuel consumption benefits of these technologies depend heavily on the vehicle application-specific duty cycle. Hybrid drivetrains provide less benefit when operation is mostly steady highway speed, because there is less opportunity for regenerative braking. Hence, they are not commonly incorporated into long-haul trucks.

In addition, *mild hybrid vehicles* have electric or hydraulic power systems that are not part of the vehicle's power train but power ancillary equipment like refrigeration or an aerial lift, allowing the primary engine to be shut off during these non-propulsion activities.

Electric trucks and buses exclusively rely on an electric motor for propulsion and on an electric storage device for all on-board systems, such as auxiliary power for hotel loads for heat, ventilation, lighting, and air conditioning. Typically, EVs draw power from an onboard battery or in some cases from ultracapacitors, overhead catenary, or inductive chargers.

Whether they are hydraulic or electric, hybrid MD/HDVs are also generally designed in either a series architecture or a parallel architecture. There is also a two-mode, or compound power split parallel electric hybrid, used in the GM-Allison hybrid electric buses, which can operate in either series, or a parallel configuration.[163] Series hybrids supply power to drive wheels directly and exclusively from the electric motor or from a hydraulic accumulator tank. In the hydraulic case, the wheels may be powered by hydraulic pressure only for a brief period, such as launching from a stop, after which the internal combustion engine takes over. Electric series hybrids typically use a small internal combustion engine (ICE) to continually recharge a battery that powers an electric traction motor. Parallel hybrid vehicles split the power transmission to the drive wheels between the ICE and the second power source (Figure 2-7).

While the range of a hybrid vehicle is usually comparable to an ICE, an electric-only MD/HDV will normally have a reduced range between charges. However, manufacturers of two MD electric trucks (E-trucks) claim to have a 100-mile-per-charge range: the Navistar eStar, with a 2-ton payload, and the Smith Newton, with an 8-ton payload.[164] Hino Trucks was honored in 2012 with the National Biodiesel Board Impact Award for being the first manufacturer to support the use of B20 biodiesel blends in a hybrid-electric truck, as well as in its complete product line of class 6 and 7 conventional trucks.[165]

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[163] See http://thisbluemarble.com/showthread.php?t=3155 and http://papers.sae.org/2007-01-0272/

[164] See 2011 DOE/EERE review at www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2011/2011_amr_01.pdf

[165] Construction Business Owners 2012. Hino Trucks Honored at Biodiesel Conference www.constructionbusinessowner.com/topics/hino-trucks-honored-biodiesel-conference

Figure 2-7: Schematic of a Parallel Hybrid-Electric Utility Truck[166]

On the transit side, electric buses that wirelessly charge through induction when they are curbed at stops have been developed.[167] Early adopters include Foothill Transit, with 12 Proterra buses, and the Utah Transit Authority.[168]

2.3.1 Penetration/Adoption

Hybrid and electric trucks still represent less than 1 percent of all commercial MD/HD trucks on the road in the United States A recent CALSTART survey of 82 fleets that represent 563,408 vehicles included only 4,381 HV/EVs, including 413 EVs, or 0.78 percent of the total. This relatively low penetration may be due to the lack of national and/or State incentives to offset incremental costs of purchase, the limited amount of in-use performance data- particularly for electric trucks- and the lack of technology standardization. The Energy Information Administration (EIA) reported that there were 865 electric and 1,025 MD/HD hybrid MD/HDVs in 2010.[169] APTA reported that in 2011 more than 35 percent of the public transit bus fleet used alternative fuels or hybrid technology, with 9 percent of buses either diesel-electric, or gasoline-electric hybrids, being operated by more than 60 public transit agencies.[170]

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[166] Mims, C. 2009. Hybrid Trucks Are Here for the Long (Medium and Short) Haul; An explosion in the number and kind of commercially available hybrid trucks means battery power isn't just for lightweight commuter vehicles anymore www.scientificamerican.com/slideshow.cfm?id=hybrid-trucks

[167] Proterra. 2012. About the EcoRide™ BE35 www.proterra.com/index.php/products/productDetail/C22/

[168] Barry, K. 2012. Induction Charging Comes to Public Transit www.wired.com/autopia/2012/12/induction-charging-bus/

[169] See Table at www.eia.gov/tools/faqs/faq.cfm?id=93&t=4

[170]"More than 35% of US public transit buses use alternative fuels or hybrid technology: Public transportation is leading the way in green vehicles: www.apta.com/mediacenter/pressreleases/2013/pages/130422_earth-day.aspx

Adoption of hybrid MD/HDVs is accelerating.[171] The 2012 industry estimates reported there are 3,500-4,500 hybrid trucks currently operating in the United States [172] and 500-1,450 electric trucks in North America.[173] More than 150 fleets use hybrid and/or electric trucks, of which there are about 40 models available.[174] Market forecasts predict anywhere from 13,000 to 39,000 hybrid and electric trucks sold annually in the United States by 2015-2017.[175,176]

Early adoption of electric trucks has occurred in States such as CA and NY that have policies and programs to encourage these EVs. Hybridization shows the greatest current benefit in vocational vehicles.[177] The most likely truck application areas for truck hybridization and electrification are municipal, delivery, and utility fleets, which tend to operate at lower speeds with frequent stop-and-go drive cycles, or which remain stopped for extended periods while operating onboard equipment, e.g., an aerial boom or a lift gate.

Major truck manufacturers are now competing in the hybrid MD/HDV market niche: Daimler/Freightliner, International, Peterbilt, Paccar/Kenworth, Navistar, and Volvo/Mack. The electric truck OEMs include Smith, Navistar, Electric Vehicles International, VIA Motors, Quantum Technologies, and Boulder EV.

In contrast to the truck market, there is already significant penetration of hybrid technology in U.S. transit bus fleets. Large public transit agencies in cities such as New York City, Chicago, Seattle and San Francisco have been at the forefront of adopting hybrid-electric buses, which now account for about 1 out of every 6 new buses that transit agencies have on order. A few agencies are pioneering plug-in electric hybrids and all-electric buses. By 2011, about 9 percent of buses were diesel-electric or gasoline-electric hybrids and more than 60 transit agencies had such buses in service.[178]

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[171] Mims, C. 2009. Hybrid Trucks Are Here for the Long (Medium and Short) Haul; An explosion in the number and kind of commercially available hybrid trucks means battery power isn't just for lightweight commuter vehicles anymore www.scientificamerican.com/slideshow.cfm?id=hybrid-trucks

[172] Mathers, J. 2011a. Hybrid Trucks: Creating Jobs, Reducing Emissions http://blogs.edf.org/innovation/2011/01/31/hybrid-trucks-creating-jobs-reducing-emissions/

[173] Walkowicz, K. 2012. Medium and Heavy Duty Vehicle Evaluations www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/veh_sys_sim/vss001_walkowicz_2012_o.pdf

[174] Mathers, J. 2011b. Work Trucks and Fuel Consumption: 2011 http://blogs.edf.org/innovation/2011/03/10/work-trucks-and-fuel-consumption-2011/

[175] ABI Research. 2009. Commercial Hybrid Vehicles: A Global Analysis of Medium- and Heavy-Duty Hybrid Trucks and Buses www.abiresearch.com/mobile/research/1001997

[176] CalStart. 2012a. Best Fleet Uses, Key Challenges, and the Early Business Case for E-Trucks www.calstart.org/Libraries/E-Truck_Task_Force_Documents/Best_Fleet_Uses_Key_Challenges_and_the_Early_Business_Case_for_E-Trucks_Findings_and_Recommendations_of_the_E-Truck_Task_Force.sflb.ashx

[177] CalStart. 2012c. Market Demand Analysis For Hybrid and Electric Trucks 2012-2016

[178] TRB/TCRP report 132 "Assessment of Hybrid Electric Transit Bus Technology," 2009 at http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_132.pdf

2.3.2 *Benefits*

According to the Transit Cooperative Research Program, diesel-electric hybrid buses can have 14 percent to 48 percent better fuel efficiency than conventional diesel buses.[179] The breakeven period of hybrid-electric transit buses for most agencies is approximately 15 years (this will obviously vary depending on current diesel costs), not accounting for reduced brake maintenance costs.[180]

With the exception of particulate matter from brake, tire, and road wear,[181] an all-electric vehicle has no mobile emissions, or direct fuel consumption. Hybrid drivetrain technologies can significantly reduce fuel consumption and vehicle emissions, depending on the drive cycle and depending on the level of hybridization, from mild to full.[182] Additionally, drivetrain hybridization and use of regenerative braking for energy recovery can reduce maintenance of some vehicle components such as brakes, based on NREL's 13 month study of Coca Cola hybrid trucks.[183]

Stored energy in an HEV also powers electric-only operation for electric Power Take-Off (ePTO) and auxiliary power generation.[184]

Wrightspeed's "Route" retrofit plug-in hybrid powertrain for MD trucks claims to increase the fuel economy from 12 mpg to 25-40 mpg in a metro drive cycle. Because the factory truck's engine and transmission are removed, the PHEV drivetrain adds no weight to the vehicle.[185]

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[179] TRB/TCRP report 132 "Assessment of Hybrid Electric Transit Bus Technology," 2009 at http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_132.pdf

[180] U.S. transit buses average approximately 30,000 miles per year and diesel buses average approximately 3.5 MPG. This means that diesel buses use on average about 8,600 gallons of fuel per year. At $4.00 per gallon each bus uses $34,400 worth of fuel per year. Most transit agencies will achieve no more than 30% reduction in fuel use, so they will save $10,000/year/bus in fuel costs. According to the American Public Transportation Association, the incremental purchase cost of a hybrid bus compared to a diesel bus is approximately $150,000.

[181] www.fhwa.dot.gov/resourcecenter/teams/airquality/brochure/particulatebrochure.pdf

[182] ils, H. 2009. Hybrid Solutions for MD Commercial Vehicles www.erc.wisc.edu/documents/symp09-Cornils.pdf

[183] See "The case for Class 8 Hybrids" at http://ev.sae.org/article/11853

[184] Freightliner. 2012. Freightliner hybrid trucks www.cleanandgreenvehicles.com/pdfs/M2eHybrid-Brochure.pdf

[185] See page 10 of CalStart. 2012d. Wrightspeed brings a CNG plug-in at http://issuu.com/kfetzer/docs/showtimes_htuf2012_issuu?mode=window&viewMode=doublePage

Figure 2-8: Hydraulic Hybrid Refuse Truck[186]

The demonstrated FE gains for hydraulic hybrid systems range between 15 percent and 50 percent, due primarily to the 71 percent brake energy recovery, which is significantly higher than that for electric hybrids. Assuming a high kinetic intensity drive cycle, such as the ones used for a refuse or delivery truck, parallel hybrids are at the lower end of this FE gain range, while series hybrids are at the upper end.[187] A field test by NREL and the United Parcel Service (UPS) measured a 13-20 percent FE gain on 11 parallel hybrid step vans versus 11 conventional vans operated by UPS in Minneapolis.[188] FedEx Ground, Purolator, and UPS report fuel savings of approximately 40 percent in tests of series hydraulic hybrids. [189] Miami-Dade's Autocar E3 refuse trucks with Parker RunWise burn 36 gallons per day versus 63 gallons for the conventional trucks.[190] Additionally, up to an eight-fold increase in brake life is reported to reduce brake fade and other brake problems. Parker claims that a series hydraulic hybrid improves drivability, smoothes braking, and boosts acceleration versus an ICE equivalent. [191]

Hybrid systems potentially also allow a vehicle that runs out of fuel or that has an ICE breakdown to still pull off the road or drive to a safe location, which is not possible in an ICE vehicle failure.

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[186] Cornils, H. 2009. Hybrid Solutions for MD Commercial Vehicles www.erc.wisc.edu/documents/symp09-Cornils.pdf

[187] DeCoster, T. 2012. Parker's hydraulic hybrid technologies www.ntea.com/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=26445

[188] National Renewable Energy Laboratory. 2012. Eighteen-Month Final Evaluation of UPS Second Generation Diesel Hybrid-Electric Delivery Vans www.nrel.gov/docs/fy12osti/55658.pdf

[189] CalStart. 2012a. Best Fleet Uses, Key Challenges, and the Early Business Case for E-Trucks www.calstart.org/Libraries/E-Truck_Task_Force_Documents/Best_Fleet_Uses_Key_Challenges_and_the_Early_Business_Case_for_E-Trucks_Findings_and_Recommendations_of_the_E-Truck_Task_Force.sflb.ashx

[190] Hybrid Truck Users Forum. 2012. More Parker Hannifin Hydraulic Hybrids http://issuu.com/kfetzer/docs/showtimes_htuf2012_issuu?mode=window&viewMode=doublePage

[191] DeCoster, T. 2012. Parker's hydraulic hybrid technologies www.ntea.com/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=26445

Since electric vehicles produce no tailpipe emissions, they also provide potential health benefits to operators through GHG reduction and complement fuel efficiency benefits. According to Smith Electric, the 20 fleets that are already using Smith trucks have prevented 15,000 hours of diesel inhalation for their drivers over five years (Figure 2-9).[192]

Figure 2-9: Smith Electric Truck[193]

2.3.3 Safety Considerations

NHTSA recognized that potential hazards involving high voltage batteries and battery-related fires are different from those posed by conventionally-fueled vehicles. In January 2012, the agency issued Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage Batteries, applicable to medium and heavy-duty hybrid vehicles.[194] The literature has reported fires that were initiated by, or involved, the energy storage systems of hybrid-electric buses and trucks. For instance, in February 2012, a Zero Truck Co. hybrid electric truck with 24 lithium ion batteries caught fire twice.[195] Firefighters did not handle the high voltage 400-volt energy storage system (ESS) to avoid electrocution, but waited for the 24 lithium ion batteries to self-extinguish. Even though this battery-related fire led to the release of hydrogen gas, there were no adverse effects as the truck was located outside.[196]

Introductions of new HEV/EVs to the market are rapidly increasing, with models from nearly every major OEM in production. One trend is that battery capacities are increasing with greater

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[192] Smith Electric Vehicles. 2012. Smith NTEA Green Truck Summit www.ntea.com/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=26498

[193] Ibid.

[194] See Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage Batteries. www.nhtsa.gov/staticfiles/nvs/pdf/InterimGuide_TowTruck_012012_v3.pdf

[195] See http://articles.mcall.com/2012-02-08/news/mc-allentown-electric-truck-fire-20120208_1_electric-truck-lithium-ion-batteries-truck-box

[196] Ibid.

vehicle electrification, owing to pressure to increase the vehicle range and to increase the range of applications for EVs.[197]

Due to their larger market penetration and longer (15 years) operational experience, hybrid and electric transit buses have more of a safety history than the more recently adopted hybrid electric trucks. Electric and hybrid-electric transit buses have been safely operated by many urban transit fleets. For example, the Santa Barbara's Municipal Transit District has operated electric buses for over two decades without any safety incidents and with only minor service interruptions. This transit fleet experience shows that centrally maintained and properly operated electric battery buses have been operating and will continue to operate safely and reliably.

Transit fleet experiences also illustrate potential battery-related hazards. In March 2012, DC Metro recalled NewFlyer/BAE buses after fire problems, although there had been only 10 such incidents in North America.[198] Fires resulted when debris in the rechargeable energy storage system on the bus roof shorted out the battery pack. The battery packs melted and smoked; however the smoke did not penetrate the passenger space.[199] In 2011, NHTSA recalled over 1,300 hybrid electric Orion VII Daimler 2007-2011 buses equipped with Lithium-ion batteries because of the potential for battery-related fire hazards.[200] Problems of smoke and overheating and the potential for fire potential were due to debris accumulation in the roof-emplaced RESS, which compromised the electrical isolation and discharged or shorted out the battery.[201]

As discussed recently in a May 2012 NHTSA workshop and in several SAE/NFPA annual EV Safety summits, the stranded energy in certain types and chemistries of lithium-ion batteries, which can enable thermal runaway given the right conditions, poses potential post-crash electrocution or fire hazards for HEVs/EVs operators and rescuers.[202]

Since the electrical systems of regular diesel vehicles are low voltage, a typical maintenance garage may not be equipped to safely service high voltage systems in hybrid-electric trucks or buses. A literature review identified several safety best practices for maintenance facilities of hybrid electric MD/HDVs: provide additional electrical safety equipment (e.g., fault ground detection and ground interrupters) and provide electrical safety training of maintenance and emergency response personnel. Specifically, high-voltage battery storage areas, and charging stations for charging several batteries at a time should be well ventilated and equipped with heat

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[197] Mackintosh, T. 2012. SAE J2990 Hybrid EV First and Second Responder Recommended Practice Overview www.sae.org/events/nevss/summit/2012_EV_Safety_Summit_mackintosh.pdf

[198] Hedgpeth, D. 2012. Manufacturer needs to repair 47 hybrid buses bought by the Metro system http://articles.washingtonpost.com/2012-03-28/local/35449072_1_hybrid-buses-new-flyer-bae-systems

[199] Ibid.

[200] See www.dhses.ny.gov/ofpc/alerts-bulletins/safety/text/2011/20110065.cfm

[201] NHTSA. 2011b. Orion VII Li-ion hybrid bus recall www-odi.nhtsa.dot.gov/recalls/results.cfm?rcl_id=11V523000&searchtype=quicksearch&summary=true&refurl=rss

[202] Harris, C. 2012. Overview of NHTSA EV Safety Program October 2012 www.sae.org/events/nevss/summit/2012_EV_Safety_Summit_harris.pdf; and www.sae.org/calendar/techsess/203434.pdf

and smoke detectors to prevent overheating and the build-up of dangerous gases from overheated batteries during charging. [203]

Since there are major differences between light-duty HEVs/EVs and their MD/HDV counterparts in terms of their power, size, weight and body ranges, appropriate consensus safety standards are being developed. These may mirror FMVSS 305 power level and battery sub-system crash integrity as assured by the NHTSA TP 3015-01 lab-testing procedure, which only applies to vehicles with a GVW less than 10,000 pounds.[204] For instance, OEMs have adopted voluntary safeguards and national and international specifications and standards for heavy-duty vehicle rechargeable storage system (RESS) safety testing. The SAE Truck and Bus Committee has issued Standard J2910 "Recommended Practice for the Design and Test of Hybrid Electric Trucks and Buses for Electrical Safety."[205]

The SAE safety performance tests for high-voltage vehicle ESSs include[206]

1. Vibration: Pack Test
2. Thermal Shock: Pack Test
3. External Short Circuit Protection: Pack Test
4. Overcharge Protection: Vehicle Test
5. Over-Discharge Protection: Vehicle Test
6. Over Temperature Protection: Vehicle Test
7. Under Temperature Protection: Vehicle Test
8. Fire Resistance – Short Duration: Pack Test
9. Fire Resistance – Long Duration: Pack Level
10. Vehicle Crash Evaluations: Vehicle Test
11. Water Intrusion Test: Vehicle Test

Eaton, a major hybrid drivetrain manufacturer lists seven engineering and conspicuity measures to reduce the risk of stray energy and electrocution.[207] These include orange coloring of all high-voltage lines, cable disconnect interlocks, ground fault detection, isolation from the vehicle chassis, and an ignition interlock that electrically isolates the ESS when the vehicle ignition is

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[203] Reich, S. L., & Kolpakov, A. 2011. Tracking Costs of Alternatively Fueled Buses in Florida www.nctr.usf.edu/2011/12/tracking-costs-of-alternatively-fueled-buses-in-florida-2/

[204] See Sept.11, 2008 TP 305-01, Laboratory Test Procedure for FMVSS 305, Electric Powered Vehicles: Electrolyte spillage and electric shock protection" at www.nhtsa.gov/Vehicle+Safety/Test+Procedures

[205] NHTSA. 2012. Electric Vehicle Safety Technical Symposium www.nhtsa.gov/staticfiles/nvs/pdf/EV_Symposium_agenda.pdf

[206] Wilson, K. 2012. SAE Cooperative Research Project to Develop Repeatable Safety Performance Test Procedures for Rechargeable Energy Storage Systems (RESS) www.sae.org/events/nevss/summit/2012_EV_Safety_Summit_wilson.pdf

[207] Eaton. 2011. Eaton Hybrid Electric Power Systems Emergency Response Guide TRDR1100 www.roadranger.com/rr/CustomerSupport/Support/LiteratureCenter/index.htm?litlibtarget=1162919212387

off. Truck OEMs are backing the reliability of their HEVs. Freightliner, for example, provides a 3-year/150,000 mile warranty on the hybrid system.[208]

The emergency response guide for Eaton HEV drivetrains outlines safety procedures for first responders that are similar to current methods used for ICE trucks.[209] The guide notes that the lithium salt, which is dissolved in an organic solvent, will not normally spill or leak if the battery is damaged. If the 1.2 gallons of contained electrolyte does leak from the battery system, it can be wiped up by a towel. In a non-fire situation, no toxic gases are emitted, and there is no inhalation hazard. If there is a fire, inhaling gas released by the battery is dangerous and the guide advises moving immediately to fresh air and seeking medical attention.

Hydraulic hybrid vehicles entail a different set of potential safety concerns than electric hybrids. The emergency response guide for Parker drivetrains states that two 20-gallon hydraulic accumulators are constantly pressurized to 2,450 psi with nitrogen gas. Nitrogen gas is not flammable and is chemically inert, but the pressure of the nitrogen gas could propel objects at deadly speed if the tank is pierced or broken. Hoses in the cradle contain 5400-psi hydraulic fluid. A hose puncture could lead to severe injection wounds by expelling high-pressure fluid, and a spray of leaking hydraulic fluid would be explosively flammable. If a hose in this system were to get loose, it could violently flail and cause death or injury by impact. If the containers of gases were pierced or opened, an explosion could also occur.

There are a variety of safety features incorporated in the hydraulic hybrid to prevent personal injury or component damage in the event of system pressure leaks or electrical failure. Safety features include a variety of fuses, discs, and valves activated by set points in velocity, temperature, or pressure. Additionally, orange coloring marks all high-pressure hoses.[210]

As one data point, following 15 months of testing HHVs, Miami-Dade County has not encountered any safety problems and has reported uptime of 99 percent in South Florida refuse collection service[211]

Parallel hybrid vehicles offer a potential safety advantage over series hybrid vehicles in the event that the hybrid drive unit fails, since the diesel powertrain remains fully functional.[212] Series hybrid vehicles are not redundantly powered, so if there is a significant hydraulic leak or a traction motor or battery failure, the vehicle is disabled and must be towed.

It is worth noting that a series HH drivetrain adds about 1,700 lbs. over a conventional drivetrain to the GVW of a truck. This is approximately 5 percent additional weight, which may affect the handling or stopping distance of the vehicle as well as its maximum payload.

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[208] Freightliner. 2012. Freightliner hybrid trucks www.cleanandgreenvehicles.com/pdfs/M2eHybrid-Brochure.pdf
[209] Eaton. 2011. Eaton Hybrid Electric Power Systems Emergency Response Guide TRDR1100 www.roadranger.com/rr/CustomerSupport/Support/LiteratureCenter/index.htm?litlibtarget=1162919212387
[210] Parker Hannifin Corporation. 2012. Parker RunWise Advanced Series Hybrid Drive AutoCar E3 First Responders Guide
[211] Hybrid Truck Users Forum. 2012. More Parker Hannifin Hydraulic Hybrids http://issuu.com/kfetzer/docs/showtimes_htuf2012_issuu?mode=window&viewMode=doublePage
[212] Freightliner. 2012. Freightliner hybrid trucks www.cleanandgreenvehicles.com/pdfs/M2eHybrid-Brochure.pdf

2.3.4 Findings and Conclusions

Hybrid-electric transit buses have demonstrated a long and safe operational history, with vehicle handling and a breakdown rate that are comparable to conventional ICE buses.[213] The recent NHTSA/ODI recall of lithium-ion RESS packages in Orion VII and Xcelsior hybrid buses[214] for potential battery-related fire hazards indicate that unforeseen safety issues occurred. The roof placement of batteries to allow for passive cooling also allowed debris and moisture to accumulate that could cause battery short-outs with the potential for a fire.

To date, no safety incidents have been reported in the shorter history of hybrid-hydraulic trucks. The underlying hydraulic technology is much more mature than that of HEVs. Multiple fail-safe design features prevent electrocution during operation of hybrid-electric vehicles, although post-crash hazards due to stranded energy may be present. In contrast to an ICE vehicle, hybrid vehicles (in particular parallel models) offer redundancy of propulsion: if one power source fails, the other can still propel the vehicle, even if it is for a short distance on electric or hydraulic system power alone.

Inputs from SMEs suggest that the full vehicle testing and modeling of EVs/HEVs is more limited for small volumes of production and downstream integration of novel RESS units by body-builders than it is for high-volume production of ICEs. Continued evaluation of best practices and lessons learned from hybridization and electrification across all adopting MD/HDV fleets would likely help to prevent failure of novel FE subsystems.

2.4 ITS and Telematics for Fuel Efficiency and Operational Safety

2.4.1 Driver and Vehicle Monitoring

Technologies that influence MD/HDV fuel efficiency can also affect driver behavior and operational safety, and vice versa. These telematics technologies include GPS-based route navigation, on-board computers that track driver and vehicle behavior, and associated mobile communications and displays that convey this information in real time to the vehicle driver and to fleet managers. Information that is typically gathered includes route choice, speed, braking, and acceleration, measured using devices such as accelerometers, GPS, and on-board cameras. Telematics systems are intended to correct the behavior of MD/HDV drivers over time to increase their fuel efficiency, either by providing real-time feedback on their driving performance or by relaying performance information to supervisors for individual driver coaching.

There are various implementations of telematics for route optimization, location, and navigation that simultaneously address the fuel efficiency and safety of vehicle operations. Camera-based

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[213] See series of NREL reports comparing new York City Transit hybrid, CNG and diesel buses at www.nrel.gov/vehiclesandfuels/fleettest/pdfs/42534.pdf and at www.nrel.gov/vehiclesandfuels/fleettest/research_hybrid_nyc.html

[214] See Recall notice at www-odi.nhtsa.dot.gov/owners/SearchResults?searchType=ID&targetCategory=R&searchCriteria.nhtsa_ids=11V523000&refurl=rss

systems such as SmartDrive record comprehensive video-based data from the road. High acceleration or force thresholds are used to filter the events that are captured. The event data are reviewed for fuel consumption and safety performance by off-site analysts, thus informing the fleet managers for driver coaching and training.[215] Non-camera based systems such as GreenRoad[216] (Figure 2-10) use accelerometers and other sensors for real-time assessment and visual feedback for driving maneuvers, e.g., with a green/yellow/red performance meter.

In addition to maintaining safe and fuel-efficient driver behavior, ITS technologies are also intended to prevent crashes, offering additional safety benefits. Although not classified as FE technologies, the Insurance Institute for Highway Safety (IIHS) has recommended four ITS crash avoidance technologies it claims have the potential to prevent or mitigate one-fourth of the 384,000 annual large truck crashes, including one-third of injury crashes and about 20 percent of the 4,100 fatal crashes.[217]

2.4.1.1 Penetration/Adoption

The penetration rate in the total population of non-privately owned commercial vehicles is estimated to increase from 7.9 percent in 2011 to 16.4 percent in 2016.[218] The market leaders include a range of different companies. Qualcomm Enterprise Services is ranked as the largest, with an estimated total installed base of approximately 450,000 units in North and Latin America. Trimble which previously mainly focused on service fleets now has a total installed base of 360,000 units following the acquisition of PeopleNet. Other companies focusing on service fleets include FleetMatics, Networkfleet, NexTraq and Wireless Matrix. Several additional companies have a broader market scope, covering both light and heavy vehicles. Examples include Telogis, Teletrac, Zonar Systems and Webtech Wireless. GreenRoad states it is used by more than 85,000 drivers worldwide, in a wide range of vehicle types, including EV vans, and NG tractors. “Green telematics” that are claimed to save fuel, reduce emissions, and optimize routing have wide market penetration and have been adopted early by large MD/HDV fleets, such as Frito Lay.[219]

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215 SmartDrive Systems. 2012. SmartDrive www.smartdrive.net/

216 http://greenroad.com

217 See “Large trucks to benefit from technology designed to help prevent crashes,” IIHS Status Report, Vol. 45, No 5, May 20, 2010.

218 www.prnewswire.com/news-releases/fleet-management---world-2012-166386546.html

219 Frito-Lay North America. 2011. Frito Lay Frito-Lay Electric Delivery Trucks hit the Green Streets of Orlando www.pepsico.com/PressRelease/Frito-Lay-Electric-Delivery-Trucks-Hit-the-Green-Streets-of-Orlando12022011.html

Figure 2-10: GreenRoad On-Board Driver Behavior and Telematics

2.4.1.2 Benefits

According to one telematics manufacturer, Telogis,[220] the FE performance spread between the best- and worst-trained drivers is about 25 percent.[221] The Telogis Fleet telemetrics program monitors when fleet vehicles violate defined speed parameters, including posted speed limits; when "hard" braking occurs; and engine off/on status, which can be critical when loading and offloading hazardous cargo.[222]

GreenRoad claims that in a case study its users' fuel consumption decreased 6-15 percent,[223] while Telogis claimed its telematics package demonstrated 11 percent fewer VMT through route optimization and monitoring driver behavior for subsequent coaching.[224] A comparison of telematic deployments for real-time fleet management and improved fuel economy found that the benefits do include safer driving, with a 50 percent crash reduction and lower insurance and crash-related costs. Additionally, the systems have led to less aggressive acceleration and significantly decreased speeding. Altogether, these behavioral changes add up to 10 percent reduced fuel consumption, a longer vehicle life, and a positive ROI in 3-6 months.[225] GreenRoad claims that its system decreases maintenance for vehicle wear by up to 10 percent.

2.4.1.3 Safety Considerations

The Federal Motor Carrier Safety Administration and the NHTSA jointly conducted the Large Truck Crash Causation Study (LTCCS) to better understand the critical events that increase the

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220 See www.telogis.com/solutions/mobile/navigation/

221 Koch, J. 2012. Technologies for increasing fuel efficiency and eliminated fuel waste www.ntea.com/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=26464

222 Telogis Fleet Safety. www.telogis.com/benefits/improve-driver-safety-and-asset-security

223 GreenRoad. 2012. http://greenroad.com/

224 Koch, J. 2012. Technologies for increasing fuel efficiency and eliminated fuel waste www.ntea.com/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=26464

225 Renaud, P. S., & Coleman, D. 2012. Telematics: real-time fleet management and improved fuel economy www.ntea.com/worktruckshow/index.aspx?id=25469

probability of large truck crashes.[226] Fatigue, alcohol, and speeding were the most common critical events for the 87 percent[227] of large truck crashes attributed to driver error, as shown in Table 1-3 above, that listed the numbers and percentage of trucks involved in crashes by safety-critical factors. Only 10 percent of crashes were attributed to vehicle issues, and only 3 percent to environmental reasons such as snow or ice. NCSA crash reports do not include FE technologies or alternative fuel tanks on state crash report forms.

Telematic technologies claim to both reduce fuel consumption and to improve safety by monitoring driver performance, including either displaying immediate feedback to the driver or recording unsafe operations for later coaching. GreenRoad claims that its users' crash-related costs decrease 50-70 percent (including lower insurance premiums) compared to baseline fleet operations. Telogis claimed that its telematics package leads to a 90 percent reduction in speeding events after one year of use; in one case study, Telogis demonstrated 11 percent fewer VMT through route optimization and monitoring driver behavior for deviations and to support coaching.[228] Although no crash reduction figures are provided, GreenRoad and Telogis data indicated that lower VMT and reduced speeding generally correlated with fewer crashes.

At the same time, a potential safety concern related to telematics systems that provide real-time feedback to drivers is the potential for additional driver distraction from these systems.

2.4.1.4 Findings and Conclusions

Driver behavior was a critical causal safety factor in the LTCCS for 87 percent of large truck crashes. By all indications, telematics and crash avoidance systems offer potential improvements in both driver safety performance and fuel efficiency. Both camera and non-camera based telematics setups are currently available and appear to be well accepted by MD/HDV fleet drivers.

2.5 FE Technologies Affecting Operations

2.5.1 Speed Limiters

Speed limiters (or speed governors) are on-board electronic control modules that limit the top speed of a vehicle to a pre-set value. They are intended to reduce the fuel consumption of MD/HDVs when traveling on highways. Since the devices also prevent excessive speeding, their safety effects have been a recurring issue in truck safety discussions. Heavy-duty trucks are delivered from the factory equipped with speed limiting devices that can be configured by the

[226] FMCSA. 2006. Report to Congress on the Large Truck Crash Causation Study www.fmcsa.dot.gov/facts-research/research-technology/report/ltccs-2006.htm#TABLE1
[227] This figure refers to all drivers in a crash.
[228] Koch, J. 2012. Technologies for increasing fuel efficiency and eliminated fuel waste www.ntea.com/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=26464

vehicle owner. However, these devices may sometimes be disabled by trucking companies in order to maximize operating speed and save travel time, as reported in Quebec, Canada.[229]

2.5.1.1 Penetration and Adoption

Electronic control modules that can be programmed to limit speed have been standard equipment in all trucks for a number of years. Typically, the top speed is programmed at the factory according to buyer specification; many U.S. trucking companies already are programming to 68 mph or slower. Estimates on how many U.S. fleets already use speed limiters ranges from 60 to 80 percent.[230]

To date, 33 countries (excluding the United States) including the world's leading developed nations, require speed limiters in heavy-duty vehicles.[231] The EU has required trucks and buses to be limited to 56 mph since 1994; Australia to 62 mph since 1990; Japan to 56 mph since 2003; and Quebec and Ontario to 65 mph since 2009.[232] A Canadian study of the environmental and safety implications of speed limiter requirements for trucks[233] reported maximal safety gains at 90 kph on uncongested roads, with safety benefits decreasing at higher speeds (105 kph) and greater traffic congestion levels. The UK and other countries have also imposed speed limiter requirements, resulting in road safety improvements. [234] The European Commission introduced Intelligent Speed Adaptation (ISA)[235] combining ITS "speed alert" technologies to automatically adjust speed limits depending on traffic conditions. NHTSA has initiated the rulemaking process for speed limiter regulations in the United States.[236]

2.5.1.2 Benefits

The FMCSA noted the European Commission (EC) multiple benefits of speed limiters:

> "*…lower fuel consumption (from 3 percent to 11%), lower maintenance costs (tires, brakes, and engine), increased road safety (fewer casualties), more relaxed driving and lower insurance premiums as a consequence of less accidents*." The negative effects noted were: *"...decreased road safety when performing an overtaking maneuver as overtaking another vehicle takes relatively longer. An indirect effect is that the long*

[229] Purchase, E. 2011. Trucking Speed Governors: PA Semi Accident Lawyers on NHTSA Study www.yourerieaccidentlawyers.com/blog/2011/09/trucking-speed-governors-pa-semi-accident-lawyers-on-nhtsa-study.shtml
[230] Trucker News Services. 2012. Speed limiter report: Trucks with devices had 50% lower 'speed-limiter relevant' crash rate www.thetrucker.com/News/Stories/2012/3/27/SpeedlimiterreportTruckswithdeviceshad50lowerspeed-limiterrelevantcrashrate.aspx
[231] Road Safe America. 2012. The Problem: Physics www.roadsafeamerica.org/docs/RSASpeedLimiterWhitePaper_0039.pdf
[232] Patton, O. 2011. NHTSA clears path for speed-limiter proposal www.truckinginfo.com/news/news-detail.asp?news_id=72581
[233] Summary Report - Assessment of a Heavy Truck Speed Limiter Requirement in Canada, TP14808 www.tc.gc.ca/eng/roadsafety/tp-tp14808-menu-370.htm
[234] FMCSA. 2008. CTBSSP SYNTHESIS 16 Safety Impacts of Speed Limiter Device Installations on Commercial Trucks and Buses A Synthesis of Safety Practice http://onlinepubs.trb.org/onlinepubs/ctbssp/ctbssp_syn_16.pdf
[235] http://ec.europa.eu/transport/road_safety/specialist/knowledge/esave/esafety_measures_known_safety_effects/intelligent_speed_adaptation_isa.htm
[236] See www.gpo.gov/fdsys/pkg/FR-2011-01-03/html/2010-33057.htm

overtaking maneuvers of vehicles fitted with speed limitation devices have the effect of reducing the average speed of other road users."

The EC report concluded overall that:

> "*It is clear that the known effects of speed limitation devices are generally very positive for drivers, for companies, for society and for the environment. The negative aspects are small and avoidable: if all the speed limitation devices were set accurately to the same speed, there would be less need for overtaking*."[237]

According to the EPA SmartWay Partnership and the Truck Maintenance Council, reducing highway speed by 5 miles per hour reduces fuel use and greenhouse gas emissions by about 7 percent while extending the life of a truck's engine, tire treads, and brakes. Decreasing MD/HDV speed by one mile per hour would increase the FE by about 0.1 miles per gallon.[238]

According to an American Transportation Research Institute survey of U.S. trucking fleets, the second most common intended goal of fleets that choose to implement speed limiters is reduction of crashes.[239]

2.5.1.3 Safety Considerations

Approximately 4,000 people die annually in multi-vehicle crashes involving large trucks, of which 98 percent are the occupants of passenger vehicles, motorcyclists, bicyclists, or pedestrians. This represents over 20 percent of all multi-vehicle crash deaths in the United States According to a recent FMCSA study,[240] approximately 15 percent of all truck crashes were identified as related to excessive speed.[241] The speed limiter-relevant crash rate[242] for trucks without speed limiters was 5 crashes per 100 trucks/year, compared to much lower 1.4 per 100 trucks/year crash rate for trucks equipped with speed limiters. The study showed that the overall crash rates for trucks without speed limiters were higher than for trucks with speed limiters, namely 16.4 versus 11 crashes per 100 trucks/year. "Results from multiple analyses indicated a profound safety benefit for trucks equipped with an active speed limiter," the report concluded. These findings are consistent with reports from countries in which speed limiters have been mandated. Road Safe America reported that fatal commercial truck accident rates in those

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[237] FMCSA. 2008. CTBSSP SYNTHESIS 16 Safety Impacts of Speed Limiter Device Installations on Commercial Trucks and Buses A Synthesis of Safety Practice http://onlinepubs.trb.org/onlinepubs/ctbssp/ctbssp_syn_16.pdf

[238] See NHTSA Oct 2010 study "Factors and Considerations for Establishing a Fuel Efficiency Regulatory Program for Commercial Medium- and Heavy-Duty Vehicles" at www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/NHTSA_Study_Trucks.pdf

[239] American Transportation Research Institute. 2011. Predicting Truck Crash Involvement: A 2011 Update www.atri-online.org/research/results/ATRI_Crash_Predictor_One_Pg_Summary_Apr_2011.pdf

[240] See FMCSA, march 21012, "Research on the Safety Impacts of Speed limiter Devices on Commercial Motor Vehicles-Phase II" at www.fmcsa.dot.gov/facts-research/research-technology/report/Speed-Limiters.pdf

[241] Trucker News Services. 2012. Speed limiter report: Trucks with devices had 50% lower 'speed-limiter relevant' crash rate www.thetrucker.com/News/Stories/2012/3/27/SpeedlimiterreportTruckswithdeviceshad50lowerspeed-limiterrelevantcrashrate.aspx

[242] Assessment of whether a crash was speed limiter-relevant was based on four types of information in the dataset used for the study: speed limit where the crash occurred, crash type (e.g., rear-end truck striking), contributing factor(s) in the crash (used to exclude crashes; e.g., weather-related), and crash narrative.

countries are lower than those in the United States.[243] In the UK, all articulated heavy-goods vehicles were speed limited after 1993 and the accident involvement rate for that vehicle class fell from 40 per hundred million vehicle kms in 1993 to 30 in 2005—a 26 percent decrease.[244] Moreover, the heavy goods vehicles involvement in fatal crashes per 100,000,000 km has dropped to 1.1 in 2005 from 3.1 in 1990, a reduction of 65 percent.[245] A large truck traveling 75 mph requires approximately one-third more distance to stop compared with a truck traveling 65 mph.[246] Speed also exacerbates the size and weight differences between large trucks and passenger vehicles, leading to more severe crashes. ABF Freight System Inc. credits slower speeds with strengthening safety performance, although the exact benefit is impossible to calculate.[247] JB Hunt Transport stated that speed limiters will create a speed differential on the highway, but that the risk from that differential is outweighed by the risk of speeding. Schneider National reported that before there were universal speed limiters in its fleet, trucks without speed limiters accounted for 40 percent of collisions while traveling only 17 percent of the route miles.[248]

An analysis of nearly 19,000 truck crashes in Kansas found that 73 percent had contributory causes related to the truck driver. The top five contributors to truck crashes were: failing to give enough attention to the task, speeding, failing to yield the right of way, improper lane changes and following another vehicle too closely. Additionally, researchers found that more truck crashes happened in locations with a high speed limit.[249] Similarly, in the FMCSA LTCCS "traveling too fast for conditions" was the most frequently cited factor in crashes where trucks were assigned the critical reason for the crash.[250] Note that this may be due to lack of driver training rather than the presence or use of speed limiters.

Data from the FARS for 2005 analyzed by the IIHS showed that an estimated 328 fatal crashes involved drivers of large trucks who were speeding, resulting in 374 deaths. About 24 percent of drivers of large trucks involved in fatal crashes in 2005 had at least one speeding conviction

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243 Road Safe America, 2009. RSA Speed Limiter White Paper www.roadsafeamerica.org/docs/RSASpeedLimiterWhitePaper_0039.pdf

244 FMCSA. 2008. CTBSSP SYNTHESIS 16 Safety Impacts of Speed Limiter Device Installations on Commercial Trucks and Buses A Synthesis of Safety Practice http://onlinepubs.trb.org/onlinepubs/ctbssp/ctbssp_syn_16.pdf

245 Road Safe America. 2012. The Problem: Physics www.roadsafeamerica.org/docs/RSASpeedLimiterWhitePaper_0039.pdf

246 McCartt, A. T. 2007. IIHS Letter re: Motor Vehicle and Carrier Safety Standards; Devices to Limit the Speed of Certain Trucks Request for Comments; Docket No. NHTSA-2007-26851 www.iihs.org/laws/comments/pdf/nhtsa_fmcsa_ds_atm_032707.pdf

247 Insurance Institute for Highway Safety. 2010. Speed Limiters in Trucks Would Serve 2 Purposes www.iihs.org/externaldata/srdata/docs/sr4508.pdf

248 Patton, O. 2011. NHTSA clears path for speed-limiter proposal www.truckinginfo.com/news/news-detail.asp?news_id=72581

249 Whistler, D. 2012. Researchers sift through crash statistics http://fleetowner.com/safety/researchers-sift-through-crash-statistics?

250 FMCSA. 2007a. Large Truck Crash Causation Study http://ai.fmcsa.dot.gov/ltccs/default.asp

within the past 3 years; this compared with 19 percent of passenger vehicle drivers involved in fatal crashes due to speeding.[251]

A NHTSA 1991 report stated that the potential crash reductions from truck speed limiters were not sufficient to justify mandating them, since they would have little effect on speeds or crash likelihood below the set maximum speed.[252] The Owner Operator Independent Drivers Association (OOIDA) cited this document in a 2007 opposing position statement.[253] OOIDA also has expressed the concern that when there is a speed differential between trucks and passenger cars, this increases the rate of lane changes and sudden braking events, and in turn increases potential for car–truck crashes. However, a number of reports have found that speed limiters actually reduce speed variability and reduce lane change and deceleration maneuvers.[254] Europe's experience with speed limiters that cap truck speeds at a speed substantially lower than the average speed of passenger vehicles also suggests no degradation in safety.

However, since the 1995 repeal of the national maximum speed limit, which was in effect at the time of the previous NHTSA conclusion, there have been widespread increases in speed limits and in average travel speeds.[255] In 2009, the American Trucking Association Safety Task Force endorsed electronically speed limiting all Class 7 and 8 trucks and setting a national 65 mph speed limit for all motor vehicles.[256]

On January 3, 2011, NHTSA published a notice granting petitions for rulemaking from American Trucking Association (ATA), Road Safe America, and nine major motor carriers. The notice announced that the agency would initiate the rulemaking process with a notice of proposed rulemaking (NPRM) on speed limiters for certain heavy trucks.

FMCSA sponsored a Transportation Research Board (TRB) study on "Commercial Truck and Bus Safety Synthesis Program (CTBSSP)," which assessed the safety impacts of speed limiter

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[251] McCartt, A. T. 2007. IIHS Letter re: Motor Vehicle and Carrier Safety Standards; Devices to Limit the Speed of Certain Trucks Request for Comments; Docket No. NHTSA-2007-26851www.iihs.org/laws/comments/pdf/nhtsa_fmcsa_ds_atm_032707.pdf

[252] See "Commercial Motor Vehicle Speed Control Devices, 1991, Report No. DOT HS 807 725. It was supportive of fleet applications of speed monitoring and speed limiting devices, but concluded that, because of the small target size, there was not sufficient justification to require the application of speed limiting devices at that time.

[253] Johnston, J. 2007. Comments of the owner-operator independent drivers association, inc in response to notice and request for comments Motor Vehicle and Carrier Safety Standards [Docket No. NHTSA-2007-26851] www.ooida.com/Issues&Actions/Regulatory/commentdocs/speed%20limiter%20comments%20final%203-27-07.pdf

[254] Varhelyi, A., & Makinen, T. 2000. The effects of in-car speed limiters: field studies http://partnet.vtt.fi/evaserve/evaserve_tool/aineisto/limiter.pdf, Toledo, H., Albert, G., and Hakkert, S., 2007. A Simulation-Based Evaluation of the Impact of Active Speed Limiters on Traffic Flow and Safety http://pubsindex.trb.org/view.aspx?id=801530

[255] McCartt, A. T. 2007. IIHS Letter re: Motor Vehicle and Carrier Safety Standards; Devices to Limit the Speed of Certain Trucks Request for Comments; Docket No. NHTSA-2007-26851 www.iihs.org/laws/comments/pdf/nhtsa_fmcsa_ds_atm_032707.pdf

[256] American Trucking Association. 2009. Expanding ATA's Safety Agenda Executive Summary www.trucking.org/ATA%20Docs/What%20We%20Do/Image%20and%20Outreach%20Programs/ART/Safety%20Task%20Force%20Report.pdf

device installations on commercial trucks and buses through a fleet survey.[257] The majority of U.S. fleet managers (although based on a low survey response rate) indicated that speed limiters were either "successful" or "very successful" in reducing crashes. In operational terms, speed limiter users believed that limiters were either "successful" or "very successful" in reducing tire wear (44%) and increasing fuel economy (76%). Almost 96 percent of respondents indicated speed limiters did not negatively affect safety or productivity.

A recent FMCSA study on the efficacy of truck speed limiters in improving road safety[258] used truck crash data collected directly from truck fleets representing 138,000 trucks and over 15,000 crashes. The findings showed strong positive safety benefits for speed limiters. Trucks equipped with speed limiters had a significantly lower overall crash rate (approximately 50%) compared to those without, and a more than three-fold decrease in speed-limiter-relevant crash rate. A less comprehensive 2009 Transport Canada study of 400 power units across two fleets concurred that lower speeds have resulted in an improved safety record. Based on the collision data reviewed, there was no evidence that speed limiters were contributing to the occurrence of collisions. In fact, there were no rear end collisions attributed to operating with a speed limiter.[259]

2.5.1.4 Findings and Conclusions

Speed limiters on MD/HDVs have demonstrated significant fuel efficiency and safety benefits, while also reducing vehicle wear and tear and maintenance costs.[260] Case studies cited above from multiple adopting countries and from U.S. truck fleets indicate net positive safety benefits from broad adoption of this FE technology. Speed limiters appear to provide a consistent and effective means to maintain lower truck speeds, save fuel, and improve road safety.

2.5.2 Idle Reduction

Idle reduction technologies allow vehicle operators to refrain from long-duration idling of the main propulsion engine by using one of several alternative technology options.[261] An idle reduction device may be either installed on board a vehicle or at a wayside station to provide auxiliary power services (e.g., heat, air conditioning, and/or electricity) instead of the main drive engine, while the vehicle is parked or stationary. On-board idle reduction technologies include:

- automatic start-stop, which shuts down the motor when the vehicle is stationary and starts it again once power is needed;
- direct-fired heaters, which are small, lightweight heaters that burn fuel from the main engine fuel supply; and

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[257] FMCSA. 2008. CTBSSP SYNTHESIS 16 Safety Impacts of Speed Limiter Device Installations on Commercial Trucks and Buses A Synthesis of Safety Practice http://onlinepubs.trb.org/onlinepubs/ctbssp/ctbssp_syn_16.pdf
[258] FMCSA. 2012b. Research on the Safety Impacts of Speed Limiter Device Installations on Commercial Motor Vehicles: Phase II www.fmcsa.dot.gov/facts-research/research-technology/report/Speed-Limiters.pdf
[259] Transport Canada. 2009b. Summary Report - Assessment of a Heavy Truck Speed Limiter Requirement in Canada www.tc.gc.ca/eng/roadsafety/tp-tp14808-menu-370.htm
[260] See IIHS Status Report, Aug.21, 2010 "Speed limiters in trucks would serve two purposes" at www.iihs.org/externaldata/srdata/docs/sr4508.pdf
[261] See EPA SmartWay verified idle Reduction options at www.epa.gov/smartway/technology/idling.htm

- Auxiliary Power Units (APUs), which are small diesel engines that are installed on the truck to provide air conditioning, heat, and electrical power to run accessories like lights, on-board equipment, and appliances.

Electrification can also provide the operator with climate control and auxiliary power without idling. This additional power may be delivered by on-board equipment (e.g., generator sets-GS, power inverters, solar panels, thermal storage systems-TSS), and/or off-board equipment (e.g., shore power at truck stops).

2.5.2.1 Penetration/Adoption

The North American Council for Freight Efficiency (NACFE) 2012 benchmarking study of anti-idling technology penetration[262] found only a modest (less than 10%) adoption rate for anti-idling technologies by the truck fleets surveyed. Penetration of anti-idling devices has been driven both by economic payoff from cumulative fuel savings, as well as by compliance with anti-idling pollution laws[263] in 46 jurisdictions in 31 States. These laws carry fines ranging from \$100 - \$25,000 per violation, and in some States, repeat offenders may be jailed.[264] A wide range of truck OEMs, drivetrain suppliers, and integrators are offering trucks with built-in idle reduction systems, including Eaton, Altec, and Freightliner.[265]

Anti-idling systems offer a good opportunity for petroleum and emissions reductions in heavy-duty vehicles—particularly vocational vehicles, as well as for long-haul routes. Common idling situations occur at worksites where power from the main engine of a vocational truck is needed to operate equipment such as an aerial lift, and when delivery vehicles stop for loading and unloading. Long-haul trucks idle for cab comfort during mandatory driver rest periods. Work truck fleets, such as Verizon, are implementing idle reduction solutions that operate the aerial using electric power, turning on the engine only when the energy storage system runs low.[266]

2.5.2.2 Benefits

Class 7 and 8 trucks alone consume over a billion gallons of diesel fuel per year when idling. Adoption of anti-idling options helped the eight study fleets surveyed by NACFE to lower their annual per truck fuel expense by an average of \$4,500.[267, 268] An Argonne National Laboratory analysis found that an idling model year 2001 truck uses 0.77 gal/hour for heating and 0.98

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[262] NACFE 2012 Anti-Idling Study http://nacfe.org/wp-content/uploads/2012/07/NACFE-2012-Anti-Idling-Study-062812.pdf
[263] See CARB HDV idle reduction requirements at www.arb.ca.gov/msprog/truck-idling/truck-idling.htm
[264] Cascade Sierra Solutions. 2011. Shorepower Truck Electrification Project www.the-step-project.org/green-answers/fleet-managers/
[265] TruckingInfo. 2012. Eaton enhances hybrid drive system for faster payback www.truckinginfo.com/news/news-detail.asp?news_id=77134, Freightliner. 2012. Freightliner hybrid trucks www.cleanandgreenvehicles.com/pdfs/M2eHybrid-Brochure.pdf, Altec Industries. 2012. Altec Green Fleet www.altec.com/green-fleet.php
[266] Beegle, B. 2012. Worksite idle reduction www.ntea.com/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=26496
[267] North American Council for Freight Efficiency. 2012b. 2012 Anti-Idling Study http://nacfe.org/wp-content/uploads/2012/07/NACFE-2012-Anti-Idling-Study-062812.pdf
[268] Ibid.

gal/hour for cooling. In comparison, a direct-fired heater only uses 0.06 gal; a storage air conditioner uses 0.2 gal; an APU uses 0.23 gal; and an electrified parking space uses between 1.7 and 2.4 kWh (between $1.00 and $2.45 per hour, well below the cost of diesel fuel consumed by idling).[269] Any truck or bus that idles 20 hours or more per week is projected to realize payback and return on investment within five years from implementing any of the idle reduction technologies.[270]

2.5.2.3 Safety Considerations

There were no safety incidents relating to the use of automatic start-stop, APUs, electrified parking spaces, or other idle reduction technologies identified in the literature. In comparison, potential safety benefits associated with idle reduction equipment adoption appear to be indirect, relating to driver in-cab air quality health impacts, and to better sleep quality. Using either electrified parking space power or an auxiliary power unit for air conditioning improves in-cab air quality for nitrogen oxide (NOx), carbon monoxide (CO), particulate matter (PM) and total hydrocarbons compared to an idling vehicle. Idling emissions can contribute to premature mortality, bronchitis (chronic and acute), hospital admissions, respiratory symptoms (upper and lower), cancer, asthma attacks, work loss days, and minor restricted activity days.[271] Given that up to one-third of drivers suffer from sleep apnea and many require continuous positive airway pressure machines in their cabs, improving conditions for sleep could reduce operator fatigue and thus reduce the potential for crashes due to sleeplessness.[272]

2.5.2.4 Findings and Conclusions

Idle reduction technologies can provide significant FE benefits to MD/HDV fleets, particularly for high-idling applications such as vocational and delivery vehicles, and long-haul sleeper tractor cabs. When used in work trucks and delivery vehicles, these FE technologies also lead to a significant reduction in point source emissions of criteria pollutants in urban locations, where human exposure is high.

Further research is needed to quantify the safety benefits of idle reduction relating to improved in-cab air quality and potentially improved operator sleep, and any related effect on maintaining hours of service safety. This literature review did not identify any safety disbenefits of anti-idling technologies.

2.6 Longer Combination Vehicles

Longer combination vehicles (LCV) allow trucks to improve efficiency and save fuel by hauling more freight in a single load by pulling multiple trailers per tractor, thereby making fewer trips and reducing the vehicle miles travelled. There are three common types: Rocky Mountain

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[269] Gaines, L. 2008. Which Idling Reduction Technologies Are the Best? www.transportation.anl.gov/pdfs/EE/533.pdf
[270] Ibid.
[271] DOE EERE. 2012b. Idle Reduction Research and Development www.afdc.energy.gov/afdc/vehicles/idle_reduction_research.html
[272] Cascade Sierra Solutions. 2011. Shorepower Truck Electrification Project www.the-step-project.org/green-answers/fleet-managers/

Doubles, Turnpike Doubles, and Triple Trailers.[273] (See Figure 5-4 for the corresponding FHWA classification graphic.[274])

2.6.1 *Penetration/Adoption*

LCVs have operated in 19 American States for a number of decades, and Canada for several decades. LCVs are suited to light, bulky freight as their maximum allowable weight is no greater than other tractor-trailers currently in operation. The Surface Transportation Assistance Act (STAA) of 1982 provided for the unrestricted use of two-trailer combinations with two 28-foot to 28.5-foot trailers on the National Network (NN).[275] The National Truck Network (NTN) comprises 209,000 miles of highways that can accommodate large trucks, including the 47,000 mile Interstate Highway System.

Some States allow LCVs with greater lengths or different tractor-semitrailer combinations, but most do not. LCVs are primarily allowed in Western States but are also permitted on some turnpikes, for example in New York and Massachusetts.[276] For example, LCVs currently operate in 16 States west of the Mississippi River and on turnpikes in 5 States east of the Mississippi River. Among the States that do allow LCVs, 11 allow operation of triples, 8 allow triples with permits, and 8 allow Rocky Mountain Doubles. Only 3 States allow operation of LCVs without restrictions.[277]

Of the eight major fleets surveyed by NACFE regarding LCV adoption, only one has begun to use double or triple trailers between 2003 and 2011.[278]

2.6.2 *Benefits*

Each LCV uses about one-third less fuel and emits one-third fewer greenhouse gas emissions than two tractor-trailers that would carry the same amount of freight.[279] LCVs introduce an increase of cargo-carrying capacity of 30 percent to 100 percent per driver. This results in fewer truck trips and fewer miles driven.[280] Fewer trucks on the road would also reduce congestion and improve safety. If freight that is currently moved by railroad is shifted to LCVs due to lower cost, the above benefits could decrease. However, the existence or extent of mode shifting and cross price elasticity has not been well studied.

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[273] DOE EERE. 2006. Fact #411: February 13, 2006 States that Allow Longer Combination Vehicles www1.eere.energy.gov/vehiclesandfuels/facts/2006_fcvt_fotw411.html

[274] See original FHWA graphic at www.fhwa.dot.gov/policy/otps/truck/wusr/fig02_2.gif

[275] The National Network consists of the Interstate System and routes designated by the FHWA in consultation with the States.

[276] Ibid.

[277] EPA. 2011a. EPA Smartway Longer Combination Vehicle Factsheet www.epa.gov/smartway/documents/partnership/trucks/partnership/techsheets-truck/EPA420F10-053.pdf

[278] North American Council for Freight Efficiency. 2012a. 2011 Fleet Fuel Efficiency Benchmark Study http://nacfe.org/

[279] British Columbia Ministry of Transportation and Infrastructure. 2011. Long Combination Vehicles Program www.th.gov.bc.ca/cvse/lcv/faqs.htm

[280] California Department of Transportation. 2009. Longer Combination Vehicles www.dot.ca.gov/hq/traffops/trucks/exemptions/lcvs.htm

2.6.3 Safety Considerations

The safety of freight moving on highways and roadways is a combination of many factors, including exposure due to vehicle miles traveled, vehicle performance characteristics, driver fatigue and capability, enforcement, roadway design, road conditions, motor carrier management, and vehicle condition and maintenance. It is difficult to isolate the impact of truck size and weight (TS&W) among these factors.

LCVs are allowed to operate on certain interstate and State highways in only 19 U.S. States primarily due to concerns over safety and potential infrastructure damage and maintenance costs.[281] An advocacy organization, OOIDA,[282] has raised safety concerns about LCVs, including the off-tracking of rear wheels when turning due to rearward amplification,[283] the incompatibility of LCVs with the turning radii of existing interchanges and intersections, their ability to maintain speed on inclines, and their potentially slower acceleration and braking in traffic. A related LCV hazard scenario and the references it is based on is discussed in detail in Chapter 5.2.5.

Statistics on LCV crashes are difficult to obtain because of the low number of vehicles and limited areas allowing them (See Section 6.6 and Figure 6-1). It is known that triple trailers tend to experience rearward amplification and can leave the lane they are traveling in, although this can be lessened by advanced connector types or with advanced active steer correction technology. Triples also require more passing length, spray more rain and snow, and have a history of being underpowered while climbing steep grades. [284]

Heavier truck traffic can deteriorate pavement structures at an accelerated rate, and serious roadway defects can subsequently lead to crashes. One combination vehicle pass may cause wear equivalent to 2,000 to 3,000 cars. Excess pavement damage from LCVs is dependent on whether the increase in vehicle weight is distributed across a sufficiently increased number of axles. [285]

In Canada, LCVs are no heavier than current tractor-trailers, yet they generally have more axles and tires to grip the road and are equipped with enhanced braking systems. Their stopping ability is generally superior to other tractor-trailers and their road damage should be no greater than current tractor-trailers. A number of Canadian reports suggest that collision rates for LCVs in Canada are relatively low, given the numerous restrictions of operation.[286, 287] A 2005 study by the Canada Safety Council found that overall there is little difference in crash rates between LCVs and other trucks when operated under similar conditions of weather, road, and driver

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[281] Adams, T., Kleinmaier, D., Marach, A., Helfrich, G., Levine, J., & Bittner, J. 2012. Longer Combination Vehicles: An Estimation of their Benefits and Public Perception of Their Use www.wistrans.org/cfire/.../CFIRE_05-01_Final_Report.pdf

[282] Owner-Operator Independent Drivers Association. 2005. Longer Combination Vehicles (LCVs) www.ooida.com/OOIDA%20Foundation/Issues/LCVs.asp

[283] Paul S. Fancher and Kenneth L. Campbell, Truck Size and Weight Study Phase I: Working Papers 1 and 2 combined: Vehicle Characteristics Affecting Safety. www.fhwa.dot.gov/reports/tswstudy/vehiclsaf.htm

[284] California Commercial Driver handbook 2010-2011 at www.dmv.ca.gov/pubs/comlhdbk/comlhdbk.pdf

[285] Ibid.

[286] British Columbia Ministry of Transportation and Infrastructure. 2011. Long Combination Vehicles Program www.th.gov.bc.ca/cvse/lcv/faqs.htm

[287] Ibid.

experience levels. However, LCVs reduce the vehicle miles traveled to move the same volume of freight, since each LCV typically carries as much freight as two single trailer trucks. Factoring in the reduced exposure and freight demand, the Safety Council concluded that LCVs have a safety record equivalent to standard trucks.[288] This may be because of the strict controls in terms of routing, weather restrictions, and driving placed on them by the carriers and by the road authorities, and because the drivers must meet higher standards of skill and experience. Given the confounding factors and smaller sample size of LCVs, it is difficult to assess their relative safety performance.

In 2010, the National Research Council reviewed and summarized a compendium of LCV studies from Canada, the United States, and Australia. A study published by the *Canadian Journal of Civil Engineering* reviewed accident rates in Alberta and concluded that from a collision rate perspective, LCVs as a group have better safety performance than other articulated trucks. Turnpike doubles, it reported, have the lowest collision rate of all articulated truck types, followed by Rocky Mountain doubles. Yet the collision rate for triple trailer combinations is higher than the collision rates for tractor semitrailers.[289]

Previous studies of potential safety impacts of TS&W policy changes have relied primarily on studies that compared crash rates of single- and multi-trailer combinations. However, most multi-trailer combinations are STAA[290] short (maximum 28' 6") doubles that are comparable in length and weight to single-trailer combinations. While these doubles are less stable than standard single-trailer tractor-semitrailers, they perform better than tractor-semitrailers in terms of their static rollover threshold and offtracking. The various LCV configurations analyzed typically fall between the tractor-semitrailer and the STAA double in terms of stability and control properties. Yet they are longer and heavier than either of those standard vehicles and they have greater offtracking. The opposite safety differences along these two dimensions are occluded in aggregate crash rate studies, making it difficult to compare the relative safety performance of different LCV configurations.[291]

The literature review offers no clear consensus on the safety of LCV operations to date and efficiency implications of expanding them nationwide. Some studies found LCVs to be less safe in terms of fatal crashes, or when cars pass LCVs. Others concluded that LCVs are safer because of lower collision rates, or lower crash costs versus tractor semi-trailers. The lack of sufficient data and controls in these studies, as well as inconsistent study methodologies, may prevent a definitive safety evaluation of LCVs at this time.[292] The Federal Highway Administration Office of Freight Management issued in December 2012 a notice soliciting bids for a new study on specific areas of Federal truck size and weight TS&W limits, their operation, and their impacts,

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[288] Ibid.

[289] Regehr, J,. Montufar, J., Rempel, G. 2008. Safety performance of longer combination vehicles relative to other articulated trucks www.nrcresearchpress.com/doi/abs/10.1139/L08-109

[290] Surface Transportation Assistance Act

[291] FHWA. 2004. Western Uniformity Scenario Analysis: A Regional Truck Size and Weight Scenario Requested by the Western Governors' Association www.fhwa.dot.gov/policy/otps/truck/wusr/chap07.htm

[292] Adams, T., Kleinmaier, D., Marach, A., Helfrich, G., Levine, J., & Bittner, J. 2012. Longer Combination Vehicles: An Estimation of their Benefits and Public Perception of Their Use www.wistrans.org/cfire/.../CFIRE_05-01_Final_Report.pdf

responding to a mandate in the Moving Ahead for Progress in the 21st Century (MAP-21) legislation.[293] This requirement to further study the issue was a compromise between proponents of allowing six-axle truck/trailer configurations to gross 97,000 pounds and opponents of any size or weight increases.

2.6.4 Literature Findings

Based on references discussed above LCVs can result in significant fuel efficiency improvement of 30 percent over conventional tractor trailers, with proportional reductions in pollutant and greenhouse emissions. Due to a decrease in VMT per unit of cargo, reduced crashes would also be expected. Whether these expected safety benefits are realized, could be influenced by whether, and to what extent, any rail cargo is diverted to LCVs. If this occurs, the benefits could be reduced. [294]

Even assuming there is no significant freight rail diversion to the highway mode, it is still difficult to extrapolate the positive safety findings from studies conducted outside the United States to U.S.-wide LCV operations because the operating environments differ. Regulatory differences could also be expected to have a significant impact on the safety of LCV operations. [295] Potential LCV hazards (see Section 5.2.5), such as offtracking and rearward amplification of LCVs require further evaluation. Advanced rearward amplification-reducing bogies or active steering correction systems may offer some safety mitigation. Operational restrictions, including strict route designations and strict driver training standards for LCVs, may also be required. Oversized and overweight LCVs may be good candidates for the use of telematics systems that monitor and help ensure the safety performance of drivers.

2.7 Tire Technologies

2.7.1 Tire Pressure Monitoring Systems and Automatic Tire Inflation Systems

Based on a representative study of hundreds of trucks, FMCSA determined that tire pressure is within 5 psi of proper pressure in only half of all truck tires.[296] In addition to programs of routine manual pressure checking and inflation procedures, a number of tire pressure monitoring systems (TPMS) and automatic tire inflation systems (ATIS) can be installed onboard MD/HDVs. These systems report the tire pressures to the driver or issue an alert if tire pressure is below a set point. Furthermore, in-pavement tire pressure pads have become available for fleet terminals that measure the tractor and trailer's tire pressure as it drives over the device. [297]

[293] Se FHWA Talking Freight at www.fhwa.dot.gov/planning/freight_planning/talking_freight/nov282012transcript.cfm

[294] FHWA. 2004. Western Uniformity Scenario Analysis: A Regional Truck Size and Weight Scenario Requested by the Western Governors' Association www.fhwa.dot.gov/policy/otps/truck/wusr/chap07.htm

[295] Ibid.

[296] Lockridge, D. 2010. FMCSA talks safety technology www.truckinginfo.com/news/news-detail.asp?news_id=70422

[297] North American Council for Freight Efficiency. 2012a. 2011 Fleet Fuel Efficiency Benchmark Study http://nacfe.org/

2.7.1.1 Penetration/Adoption

According to NACFE, only automatic tire pressure inflation systems on trailers had significant adoption rates, with nearly 30 percent of the trailers in the eight surveyed fleets incorporating ATIS by 2011.[298] There does not seem to be a predominant tire FE technology or practice emerging, so NACFE is continuing annual tire pressure benchmarking surveys[299] of fleet adoption and FE gains. Most fleets still choose to manage correct tire pressure through routine manual maintenance rather than procuring systems that will monitor and inflate tires on their own. [300] Approximately only 5 percent of national truck fleets employ TPMS technology. The low penetration rate appears to be based on concerns of system reliability, maintenance costs, and initial system costs.[301]

2.7.1.2 Benefits

Correct tire inflation is important for achieving optimal fuel economy in commercial motor vehicles (CMVs). Preliminary results from a FMCSA field operational test with one truck fleet indicated a 1.8 percent increase in FE due to TPMS and found that the tires on non-equipped control trucks showed faster wear than those on TPMS trucks. The extra wear corresponded to one extra road call per year.[302] Another FMCSA study of three different TPMS models recorded a fuel economy increase of 1.4 percent and positive ROI in less than one year. Tread wear improvements were measurable, especially on the drive tires. According to the study, some drivers who were initially wary of the systems eventually asked management to equip entire fleets with TPMS and ATIS.[303]

TPMS systems, whether on-board or terminal-based, greatly assist in a fleet's ability to monitor, take action and continue to educate drivers and maintenance technicians on the importance of correct tire inflation for both FE gains and for safe stopping distance when braking.

In combination with a telematic system, TPMS can also report tire pressures to a web portal and warn the fleet manager or dispatcher of underinflated tires. One TPMS manufacturer claims that this extends the life of tires up to 20 percent.[304]

NACFE studies reported that fleets adopting tire pressure inflation and monitoring systems for use on vehicles, using drive-over tire pressure measurement mats or strictly requiring drivers to routinely check pressure saved $4,500 per year.[305]

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[298] Ibid.
[299] See http://nacfe.org/wp-content/uploads/2012/07/NACFE-2012-Tire-Pressure-Study-062812.pdf
[300] North American Council for Freight Efficiency. 2012a. 2011 Fleet Fuel Efficiency Benchmark Study http://nacfe.org/
[301] Lockridge, D. 2010. FMCSA talks safety technology www.truckinginfo.com/news/news-detail.asp?news_id=70422
[302] Ibid.
[303] Park, J. 2012. DOT study proves ROI on tire inflation and pressure monitoring systems www.truckinginfo.com/news/news-detail.asp?news_id=76201
[304] WABCO. Integrated Vehicle Tire Pressure Monitoring (IVTM) www.wabco-auto.com/ivtm
[305] North American Council for Freight Efficiency. 2012c. 2012 Tire Pressure Study http://nacfe.org/wp-content/uploads/2012/07/NACFE-2012-Tire-Pressure-Study-062812.pdf

2.7.1.3 Safety Considerations

Tire under-inflation results in irregular tire wear, which can reduce the ability of tread to grip the road in adverse conditions.[306]

Currently, NHTSA requires TPMS for proper tire inflation for light duty cars and trucks in view of safety benefits.[307] A concern with some automatic tire inflation systems noted in the NACFE reference cited is that a driver may be over reliant on TPMS/ATIS and continue to drive on a flat tire, expecting it to self-inflate, only to have a blowout later if the ATIS fails.[308] As with any new technology, driver education is required to understand the limitations of the technology.

2.7.1.4 Literature Findings

A tire can lose up to half of its air pressure and still not appear to be flat, so either regular checks by the driver, or automatic systems such as TPMS/ATIS, are critical for both vehicle safety and for optimal fuel efficiency. It is not clear from the available literature whether such automatic systems for MD/HDVs lead to safer vehicle operations, versus diligent visual checking procedures. However, there is also no evidence to indicate that TPMS/ATIS adoption leads to lower safety performance. Given that a wide range of tire checking diligence may be expected across fleets and drivers, automatic systems appear likely to raise the lowest common denominator of diligence, and therefore operational safety.

2.7.2 Single Wide Tires

Although heavy and medium trucks still most commonly use double tires at each wheel site, over the past decade major tire suppliers have begun to offer single wide base – or "super single" – tires for MD/HDVs. With single wide tires, only one tire is installed per wheel site instead of two (Figure 2-11); meaning an 18-wheeler becomes a 10-wheeler. This design change is intended to improve fuel efficiency through a combination of decreased rolling resistance, lower aerodynamic drag, and reduced weight.

Figure 2-11: Single Wide Base Tires Replacing Duals at Each Wheel Site[309]

[306] HCI Corporation. 2011. Tire-SafeGuard www.tiresafeguard.com/
[307] See Safercar.gov TPMS postings at www.safercar.gov/Vehicle+Shoppers/Tires/Tires+Rating/TPMS
[308] North American Council for Freight Efficiency. 2012a. 2011 Fleet Fuel Efficiency Benchmark Study http://nacfe.org/
[309] North American Council for Freight Efficiency. 2010. Executive Report – Wide Base Tires

2.7.2.1 Penetration/Adoption

More than two decades ago, single wide tires were seen as an alternative to the conventional dual truck tire assembly that had been the industry standard since its introduction in the early 20th century. Numerous fleets and owner operators have adopted this technology.[310]

Two of the eight major truck fleets surveyed by NACFE have exclusively adopted single wide tires, driven by weight reduction and fuel economy goals.[311] One fleet surveyed by NACFE had no plans to adopt over concerns about the initial cost and the break even period. All surveyed fleets believed that tire and wheel availability and other issues that prevented widespread single wide tire adoption no longer exist. These fleets indicated that pressure from heavier tractors—due to new EPA emissions equipment—and from denser loads—led them to consider weight-saving measures, including wide-base tires.

2.7.2.2 Benefits

Studies indicate that single wide tires may yield fuel savings of 2-6 percent, as a result of reduced aerodynamic drag, rolling resistance, and weight reduction.[312,313] Single wide tires were also reported to improve vehicle stability and handling, especially for tanker trailers by allowing the tank to be mounted lower.[314] A lower center of gravity should reduce the risk of vehicle rollover.

The total weight savings for a typical combination truck using single wide base tires on its drive and trailer axle ranges from 800 to 1,000 pounds. The weight savings reduce fuel consumption or increase cargo capacity for trucks that are weight-limited. Single wide tires may offer other benefits in combination with improved truck stability.[315]

Using single wide tires, there are also fewer tires and no hard-to-reach inner tires. Most uneven tire wear occurs because one dual has less air in it than another. That problem is eliminated with singles.[316] Increased brake life is also a possible benefit of using single wide tires. Depending on axle width and wheel offset, more of the brake drum is exposed to open air, allowing the drum and shoe to stay cooler, with claimed benefits of up to an extra 20,000 miles of brake life per tractor.

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http://nacfe.org/wp-content/uploads/2010/12/NACFE-ER-1002-Wide-Base-Tires-Dec-2010.pdf

[310] Ibid.

[311] North American Council for Freight Efficiency. 2012a. 2011 Fleet Fuel Efficiency Benchmark Study at www.greenfreightandlogistics.org/news/2011-fleet-fuel-efficiency-benchmark-study//

[312] Salari, K. 2012. DOE's Effort to Reduce Truck Aerodynamic Drag through Joint Experiments and Computations www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/veh_sys_sim/vss006_salari_2012_o.pdf

[313] North American Council for Freight Efficiency. 2010. Executive Report – Wide Base Tires http://nacfe.org/wp-content/uploads/2010/12/NACFE-ER-1002-Wide-Base-Tires-Dec-2010.pdf

[314] EPA. Smartway: a glance at clean freight strategies: single wide based tires at www.epa.gov/smartway/forpartners/documents/trucks/techsheets-truck/EPA-420-F10-041.pdf

[315] EPA. 2012. Low Rolling Resistance Tires A Glance at Clean Freight Strategies www.epa.gov/smartway/documents/partnership/trucks/partnership/techsheets-truck/EPA-420-F10-041.pdf

[316] Overdrive. 2012. Single-Minded www.overdriveonline.com/single-minded/

2.7.2.3 Safety Considerations

A potential safety concern is that drivers may lose control when a single wide tire blows out on the highway, since there is no remaining dual to shoulder the load on that wheel site. This appears unlikely to happen because most combination trucks have tandem axles, so they can still pull over to the shoulder if a wide base tire fails. The single wide tires also lower the vehicle's center of gravity, so the vehicle may be less likely to lose control than one with dual wheels.[317] When a single wide tire fails, the vehicle is certainly down and cannot be "limped in" to the nearest point of service, as can be done with dual wheels. However, with the implementation of new CSA rules "limping in" may no longer be accepted practice.[318]

Single tires eliminate the potential for the two tires on a dual wheel to have different pressures. Unequally inflated dual wheel tires shift the load to the tire with higher pressure. This may not be visually apparent and therefore is likely to occur without the driver's knowledge, increasing the probability of a blowout.[319] Fleets that have adopted single wide tires report that breakdowns with wide base tires occur less frequently because the driver can visually detect when they have a low tire and address the issue sooner than on a vehicle with dual wheels.[320]

Testing by tire manufacturers and fleets suggests that traction of wide base tires is comparable to that of dual tires.[321]

2.7.2.4 Findings and Conclusions

Given advances in single wide tire design over the past decade, and in light of positive fuel efficiency gains and safety experience to date reported by NACFE and major fleet adopters, wide base tires were found to offer a straightforward and low-risk way to reduce weight and to improve the FE of MD/HDVs fleets by a significant 2-6 percent.

2.7.3 Low Rolling Resistance Tires

Overcoming tire rolling resistance accounts for nearly 13 percent of the total energy required to keep a combination truck in motion.[322] Tire design plays a key role in determining the level of rolling resistance, and innovations in tire tread design have made it possible to decrease resistance. While there have been indications that for some rugged duty cycles these lower rolling resistance tread designs may not provide sufficient traction, most long-haul highway-based trucks have already adopted lower rolling resistance tires.[323]

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[317] Ibid.
[318] NACFE 2010 Wide base tires report at http://nacfe.org/wp-content/uploads/2010/12/NACFE-ER-1002-Wide-Base-Tires-Dec-2010.pdf
[319] Overdrive. 2012. Single-Minded www.overdriveonline.com/single-minded/
[320] See ref 282 NACFE 2010 report
[321] North American Council for Freight Efficiency. 2010. Executive Report – Wide Base Tires http://nacfe.org/wp-content/uploads/2010/12/NACFE-ER-1002-Wide-Base-Tires-Dec-2010.pdf
[322] EPA. 2011c. SmartWay Technology Program: Verified Low Rolling Resistance Tires www.epa.gov/smartway/technology/tires.htm
[323] Carbon War Room Research & Intelligence Group. 2012. Unlocking fuel-saving technologies in trucking and fleets

2.7.3.1 Penetration/Adoption

All eight fleets surveyed by NACFE, representing 75,000 tractors and 130,000 trailers, have adopted low rolling resistance tires.[324] The EPA references a test of LRR tires on 15 fleets that logged 57 million miles.[325] More extensively, all non-short-haul heavy-duty tractors that pull 53-foot or longer box-type trailers in California have been required to install LRR tires since 2010 following the adoption of an Air Resources Board greenhouse gas reduction regulation.[326]

2.7.3.2 Benefits

The EPA's SmartWay Partnership states that the FE improvement due to LRR tires is 2-5 percent. SmartWay acknowledges that LRR tires may have slightly decreased tread life, but cites a manufacturer report that found the tires to wear at a rate comparable to conventional tires.[327] These improvements are achieved when verified low rolling resistance tires are installed on all of the axle positions of the tractor and trailer and when all tires are properly inflated according to the manufacturer's specifications.[328]

2.7.3.3 Safety Considerations

In a 2009 NHTSA study of low and standard rolling resistance tires for light-duty vehicles, the tire models tested were found to show a strong and significant relationship between lower rolling resistance and lower wet slide number (i.e., locked-tire wet traction coefficient). This may be significant to light-duty vehicles that are not equipped with anti-lock braking system (ABS), since the wet slide number relates most closely to locked-wheel emergency stops on wet road surfaces. For newer vehicles with ABS or electronic stability control systems, the tradeoff was predicted to be less significant.[329] However, it is important to note that ABS have been required by NHTSA on all trucks and buses since the 1997-1999 implementation timeframe.[330] A recent

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http://carbonwarroom.com/sites/default/files/reports/Unlocking%20Fuel%20Saving%20Technologies%20in%20Trucking%20and%20Fleets%20(Carbon%20War%20Room).pdf

[324] North American Council for Freight Efficiency. 2012a. 2011 Fleet Fuel Efficiency Benchmark Study http://nacfe.org/

[325] EPA. 2012. Low Rolling Resistance Tires A Glance at Clean Freight Strategies www.epa.gov/smartway/forpartners/documents/verified/420f12024.pdf

[326] California Air Resources Board. 2012. Heavy-Duty (Tractor-Trailer) Greenhouse Gas Regulation www.arb.ca.gov/cc/hdghg/hdghg.htm

[327] EPA. 2012. Low Rolling Resistance Tires A Glance at Clean Freight Strategies www.epa.gov/smartway/documents/partnership/trucks/partnership/techsheets-truck/EPA-420-F10-041.pdf

[328] EPA. 2011c. SmartWay Technology Program: Verified Low Rolling Resistance Tires www.epa.gov/smartway/technology/tires.htm

[329] Evans, L. R., MacIsaac, J. D., Harris, J. R., Yates, K., Dudek, W., Holmes, J., Popio, J., Rice, D., & Salaani, M. K. 2009. NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 2 – Effects of Tire Rolling Resistance Levels on Traction, Treadwear, and Vehicle Fuel Economy www.nhtsa.gov/DOT/NHTSA/NVS/Vehicle%20Research%20&%20Test%20Center%20%28VRTC%29/ca/Tires/811154.pdf

[330]Jermakian, J.S. 2012. Crash avoidance potential of four large truck technologies. *Accident Analysis and Prevention* 49:338-46, at www.iihs.org/iihs/topics/t/crash-avoidance-technologies/qanda#antilock-brakes

Transport Canada study[331] of Class 8 long-haul trucks equipped with SmartWay-certified LRRs demonstrated safe traction performance in winter conditions, while increasing fuel economy and reducing emissions.

2.7.3.4 Findings and Conclusions

Although safety trade-offs from lower traction are theoretically possible, the literature search did not identify data on safety impacts of LRR tires in MD/HDVs, or reports of safety hazards from lower LRR road grip in snow, ice or wet conditions that could result in potential degraded handling or longer braking distance. The average age of Class 8 tractors, which stand to benefit the most from LRR tires, is approximately 9 years.[332] This means that LRR replacement tires would have to be installed to continue the FE benefits over the life of the vehicle.

2.8 Aerodynamic Components

Aerodynamic technologies minimize drag and improve the airflow around a moving MD/HDV. Examples of aerodynamic technologies include gap fairings that reduce turbulence between the tractor and trailer, side skirts that minimize wind under the truck body, and rear fairings that reduce turbulence and pressure drop at the rear of a trailer. Additionally, streamlined side mirrors, roof deflectors, cabin extenders, and other systems are available.

The EPA SmartWay program has verified four categories of aerodynamic components through its fuel efficiency technology certification:[333]

- Trailer Gap Reducer—fairings attached to front of trailer
- Trailer Boat Tail—fairings attached to rear of trailer
- Trailer End Fairing—attached to underbody of trailer
- Trailer Skirts—fairings attached to sides of trailer underbody

2.8.1 Penetration/Adoption

Eight major truck fleets, representing 75,000 tractors and 130,000 trailers, participated in a benchmarking technology adoption study led by NACFE from 2003 to 2010. The tractors studied drove over 3 billion miles in 2010, by which time all eight fleets had adopted most, if not all of the available tractor aerodynamic features, including bumpers, mirrors, roof fairings, chassis skirts, and minimized fifth wheel height. OEMs are now typically filling the gaps between bumpers and fenders.[334] Figure 2-12 illustrates the relative adoption rate of aero FE technologies, relative to other FE technologies discussed here.

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331 www.tc.gc.ca/eng/mediaroom/releases-2013-h007e-7042.htm and Packed snow performance of low rolling resistance class 8 heavy truck tires - Feb. 2013 Executive Summary at www.tc.gc.ca/eng/programs/environment-etv-packed-snow-performance-eng-2913.htm

332 Heavy-Duty Truck Fleet Ages as Carriers Seek Cost Savings. www.trustheart.com/news-bulletins/ltl-and-tl-bulletins/91-heavy-duty-truck-fleet-ages-as-carriers-seek-cost-savings

333 EPA. 2011b. SmartWay Technology Program: Verified Aerodynamic Technologies at www.epa.gov/smartway/forpartners/technology.htm

334 North American Council for Freight Efficiency. 2012a. 2011 Fleet Fuel Efficiency Benchmark Study / http://nacfe.org

While aerodynamic improvements for tractors are already being widely adopted, aerodynamic devices for trailers are not yet as well used. In part, this is because most trailer aerodynamic devices were not widely available or adopted until recently. For instance, boat tails on the backs of trailers have only been available since 2007. Trailer skirts have been quickly adopted in the past 3 years, accelerated both by a California Air Resources Board (CARB) requirement and by the increased price of fuel—given that trailer skirts offer greater FE benefit than other component types. In December 2008, CARB adopted a regulation to reduce greenhouse gas emissions from 53-foot or longer box-type tractor-trailers. A combination of tractor and trailer aerodynamics and the use of low rolling resistance tires are mandated by the CARB regulation.[335] Although the NHTSA/EPA MY2014-18 regulation does not cover trailers, the adoption rate trends shown in Figure 2-12 suggest that the gap between tractor and trailer aerodynamics may narrow in the next few years.

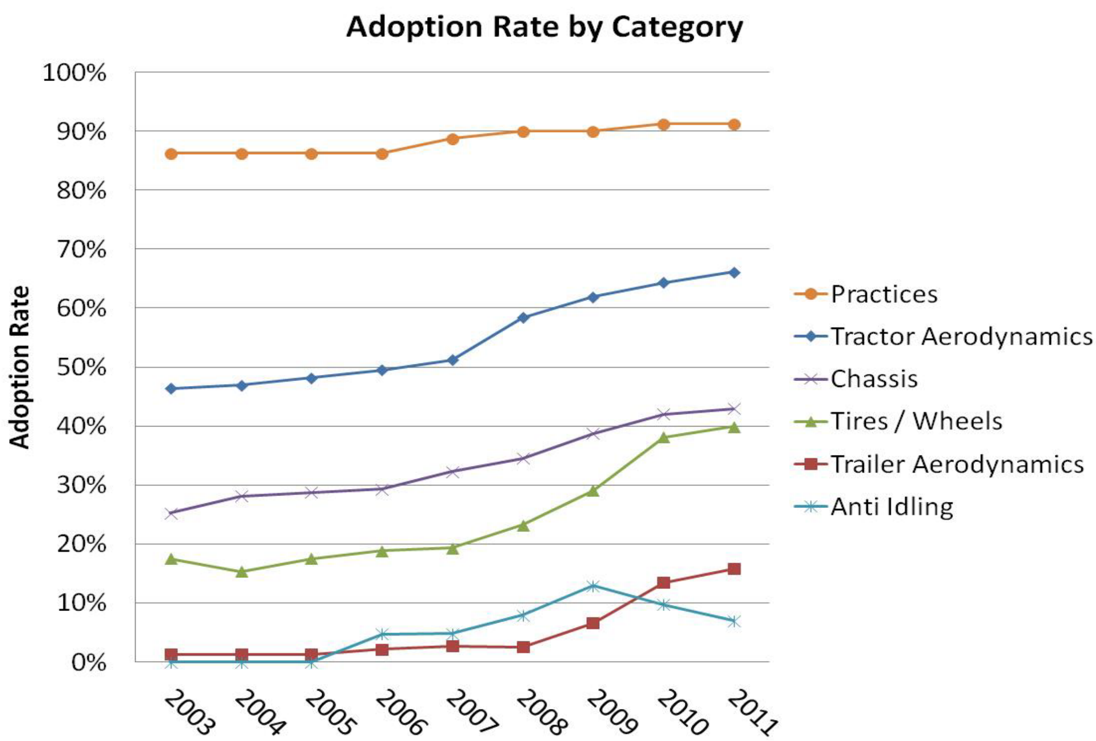

Figure 2-12: FE Technology Adoption Across Eight Major Fleets[336]

A number of new concepts have recently emerged for trailer aerodynamic upgrades. For example, a device known as an undertray fairing may be substituted for the more prevalent truck skirts and boat tails. Competition of aero designs may accelerate aerodynamic devices adoption by long-haul truck fleets.[337]

[335] California Air Resources Board. 2012. Heavy-Duty (Tractor-Trailer) Greenhouse Gas Regulation www.arb.ca.gov/cc/hdghg/hdghg.htm

[336] North American Council for Freight Efficiency. 2012a. 2011 Fleet Fuel Efficiency Benchmark Study http://nacfe.org/

[337] Ibid.

For package delivery and utility trucks that operate in stop-start mode, or short ranges, aero devices add weight and may reduce fuel efficiency, although medium-duty trucks operating on highway-intensive duty cycles offer benefits and growth potential for aerodynamic upgrades.[338]

2.8.2 Benefits

According to a DOE modeling study and testing, aerodynamic devices offer significant potential to improve the fuel efficiency of medium and heavy-duty trucks. Specifically, for a box-type tractor-trailer, the combination of a gap reducer, a trailer skirt, and a boat tail can yield 26 percent drag coefficient reduction. This corresponds to FE gains respectively of a:

- gap reducer: 1-2 percent,
- underbody skirt: 5-7 percent, and
- boat tail: 4-7 percent.

DOE indicates that a 12 percent reduction in fuel use from decreased aerodynamic drag would translate to about 3.2 billion gallons of diesel fuel saved per year and 28 million tons of CO2 emission reduction for a Class 8 tractor-trailer. Also that that additional FE reductions could result from combining aerodynamic upgrades with single wide tires.[339]

The 2010 National Research Council (NRC) report estimated that the fuel efficiency improvement available today for trailer aerodynamics is 5.5 percent but concurs with the DOE analysis that the benefit can increase to 11.5 percent in just a few years.[340] EPA stated that using fairings can increase fuel efficiency by as much as a 15 percent when applied to an early model combination tractor-trailer truck and 3-11 percent when applied to a newer Class 8 truck in long-haul highway type operation.[341] Manufacturers claim that using only one aerodynamic surface, such as a rounded air deflector, can increase fuel efficiency by up to 5 percent, reducing fuel use by about 80 gallons, thus saving over $100. The range of boat tails tested in another study, ranging from a 2 feet to 5 feet extension, were reported to reduce tractor-trailer fuel consumption between 4.7 percent and 7.3 percent, similar to the DOE figures.[342]

According to the NACFE technology adoption study, large truck fleets have reported varying degrees of real world fuel economy performance gains from 2 percent to about 5 percent for aerodynamic devices.[343]

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[338] Carbon War Room Research & Intelligence Group. 2012. Unlocking fuel-saving technologies in trucking and fleets
http://carbonwarroom.com/sites/default/files/reports/Unlocking%20Fuel%20Saving%20Technologies%20in%20Trucking%20and%20Fleets%20(Carbon%20War%20Room).pdf
[339] Salari, K. 2012. DOE's Effort to Reduce Truck Aerodynamic Drag through Joint Experiments and Computations
www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/veh_sys_sim/vss006_salari_2012_o.pdf
[340] National Research Council. 2012. Review of the 21st Century Truck Partnership, Second Report
www.nap.edu/openbook.php?record_id=13288&page=R1
[341] EPA. 2011b. SmartWay Technology Program: Verified Aerodynamic Technologies
www.epa.gov/smartway/technology/aerodynamics.htm
[342] Patten, J., Poole, G., Mayda, W., & Wall, A. 2010. Trailer Boat Tail Aerodynamic and Collision Study
www.tc.gc.ca/eng/roadsafety/safevehicles-motorcarriers-environment-boat-tails-1307.htm
[343] California Air Resources Board. 2012. Heavy-Duty (Tractor-Trailer) Greenhouse Gas Regulation
www.arb.ca.gov/cc/hdghg/hdghg.htm

2.8.3 Safety Considerations

Many boat tail configurations that provide high drag reduction possibilities include boat tail material that is as low as 44 inches from the ground, which could cause a vehicle to strike the boat tail before or instead of the rear impact guard. For many configurations, this material is sufficiently short that the collisions are mostly grille or hood strikes.[344] This Transport Canada aerodynamics air flow analysis and collision estimation of boat tails was based on scale models and wind tunnel testing. It concluded that in truck-truck collisions, class 4-6 straight trucks with cab-over engine designs have the greatest potential for occupant injury. If a cab-over engine driver rear-ends a truck equipped with boat tails, the horizontal boat tail structural member could protrude through the windshield.[345] The data required to quantify these strikes were not included in the report, however, and the report recommended further study to expose cab-over engine vehicle populations in the analysis. No specific windshield strike cases were found in literature. The Transport Canada study identified tradeoffs between optimal FE gain and minimizing the risk of other vehicles' collision with the boat tail.[346]

Even though the bottom panel of boat tail configurations provides up to 20 percent of the overall aerodynamic benefit, the study concluded that it could result in safety hazard in colder climates. Ice and snow can potentially accumulate on the bottom panel and later become dislodged, creating dangerous shedding conditions for cars behind the truck.

Damage from road debris, or detachment of aerodynamic skirts and tails in normal vehicle operation are a potential safety issue for aerodynamic features, particularly for underbody devices. However, no reported incidents of aerodynamic component detachment or structural failure while en route could be found in the literature. Trailer skirt developers have prioritized the design of components that are resilient against road damage. Various aerodynamic skirts have been in continuous use on MD/HDVs in European and certain Asian countries for over two decades, where regulatory and economic factors promote both fuel efficiency and the provision of vulnerable road user (VRU) underride protection.[347] Newer skirts are typically constructed of fiber-reinforced plastic and appear to resist damage when repeatedly impacted by curbs, loading dock ramps, railroad crossings, and snow (Figure 2-13).[348] Some designs have full-flex struts that allow them to bend up to 90 degrees rather than snap, as in older monolithic designs, and they weight as little as 190 pounds.[349,350] There is a relatively low impact on the vehicle weight—approximately 0.25 percent of an 80,000 GVWR.

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[344] Patten, J., Poole, G., Mayda, W., & Wall, A. 2010. Trailer Boat Tail Aerodynamic and Collision Study www.tc.gc.ca/eng/roadsafety/safevehicles-motorcarriers-environment-boat-tails-1307.htm
www.tc.gc.ca/eng/roadsafety/safevehicles-motorcarriers-environment-boat-tails-1307.htm
[345] Ibid.
[346] Ibid.
[347] National Research Council. 2010a. Technologies and Approaches to Reducing the Fuel Consumption of MD/HD Vehicles www.nap.edu/openbook.php?record_id=12845&page=R1
[348] www.youtube.com/watch?v=PzGhXtJyIBU
[349] Freight Wing Incorporated. 2011. Aeroflex www.freightwing.com/aeroflex.php
[350] Green Big Truck. 2010. Laydon Composits Gets CARB Certified for Trailer Skirt Products http://greenbigtruck.com/2010/02/laydon-composits-gets-carb-certified-for-trailer-skirt-products/

Figure 2-13: Aerodynamic Trailer Skirt Survivability to Impacts[351]

Aerodynamic features can provide both truck occupant and non-occupant safety benefits unrelated to reducing fuel consumption and greenhouse gas emissions. The safety benefit of skirts that also act as VRU sideguards in certain operating environments are discussed separately below.

2.8.3.1 Side Skirts

There are various reports that side skirts and boat tails improve trailer-tracking stability, especially in crosswinds. Additionally, skirts appear to significantly reduce road spray from trailer tires, improving visibility for nearby vehicles on the highway. One trailer skirt manufacturer, Laydon Composite, states that its devices are both damage resistant and comply with the European heavy truck sideguard regulation.[352] European Council Directive 89/297/EEC (ECD, 1989) mandates side under-ride protection on trucks over 3.5 tons to prevent pedestrians, bicycle riders, and motorcyclists from falling and being crushed under the wheels of a moving vehicle.[353] Based on data from the European Union, the number of deaths and serious injuries for VRUs involved side-impact crashes with heavy vehicles has been reduced since the universal implementation of sideguards in 1986 in the United Kingdom[354] and on the Continent in 1989.[355]

Side impacts comprise a large subset of VRU-truck fatalities.[356] In the United States, 55 percent of bicyclist fatalities and 29 percent of pedestrian fatalities involving tractor trailers in 2005-2009 followed initial point of impact with the right or left sides of the truck.[357] The

351 Freight Wing Incorporated. 2011. Aeroflex www.freightwing.com/aeroflex.php
352 National Research Council. 2010b. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles www.nap.edu/openbook.php?record_id=12845&page=R1
353 European Union. 1989. European Council Directive 89/297/EEC http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31989L0297:EN:HTML
354 UK Road Vehicles (Construction and Use) Regulations 1986. www.legislation.gov.uk/uksi/1986/1078/made
355 Patten, J. D., & Tabra, C. V. 2010. Side Guards for Trucks and Trailers Phase 1: Background Investigation www.safetrucks.ca/resources/National_Research_Council_Truck_Side_Guard_Study_2010-03-01.pdf
356 Ibid.
357 NTSB, Safety Recommendations H-14-001 through -007, 2014. www.ntsb.gov/safety/safety-recs/RecLetters/H-14-001-007.pdf

corresponding side-impact fractions of bicyclist and pedestrian fatalities involving single-unit trucks during 2005-2009 were 44 percent and 25 percent.[358] Sideguard devices that comply with the EU-directive have been correlated with a 61 percent bike fatality reduction in side collisions with heavy trucks in the United Kingdom following implementation on most of its truck fleet. Two examples of safety-driven truck side-guard adoption in the United States are the municipal truck fleets of Portland, Oregon, which performed the retrofits in 2008[359], and Boston, MA, which fitted its municipal trucks in 2013.[360] An ordinance requiring the Washington, D.C. municipal fleet to be fitted with sideguards was enacted in 2008.[361] None of these safety-driven efforts has simultaneously considered impacts on vehicle fuel efficiency.

It is unclear whether all U.S. models of aerodynamic side skirts would also provide comparable safety benefit for VRU under-ride protection. This question, as well as a comprehensive cost-benefit analysis that jointly considers VRU safety and fuel efficiency benefits across different MD/HDV classes and operating environments, could benefit from further study. Such a study could explore the effects on VRU safety and fuel consumption of a design that attempts to address both issues.

If VRU under-ride protection were considered as a core function of the side skirt, the skirt's impact resistance, geometry, and visibility would need to be considered in tandem with its fuel efficiency effects. This could mean minimizing gaps in coverage, increasing conspicuity, and ensuring a minimum lateral resistance to force, commensurate with the impact of a cyclist or pedestrian, or possibly of a motorcyclist, lower ground clearance, making the sideguard flush with the side of the truck body, and by extending the sideguard longitudinally.[362]

2.8.4 Findings and Conclusions

Aerodynamic technologies offer significant fuel savings in the 5-15 percent range for MD/HDVs, depending on how full a package is installed, and on the drive cycle of the vehicle. Maximum benefit will be realized for long-haul Class 8 trucks, as recognized in the EPA SmartWay program. While the literature indicates that some users have concerns about damage to underbody fairings or skirts, there were no documented incidents of any safety-critical damage.

358 NTSB, Crashes Involving Single-Unit Trucks that Resulted in Injuries and Deaths, 2013. www.ntsb.gov/safety/safety-studies/Documents/SS1301.pdf
359 City of Portland. 2007. Improving Bicycle Safety in Portland www.portlandonline.com/shared/cfm/image.cfm?id=191337
360 City of Boston Mayor's Office of New Urban Mechanics http://newurbanmechanics.org/project/vehicle-side-guards/
361 Patten, J. D., & Tabra, C. V. 2010. Side Guards for Trucks and Trailers Phase 1: Background Investigation www.safetrucks.ca/resources/National_Research_Council_Truck_Side_Guard_Study_2010-03-01.pdf
362 Riley, B. S., Penoyre, S., & Bates, H. J. 1985. Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards http://trid.trb.org/view.aspx?id=237955

2.9 Lightweight Materials

Use of lighter materials substitution for steel in body and chassis components also reduces vehicle fuel consumption, although material strength and the role of vehicle mass and design for crash safety must be considered. According to the DOE Materials Technology Program, reducing the vehicle weight by 10 percent can improve the fuel economy by 6 to 8 percent.[363] With 75 percent of vehicle fuel consumption directly related to factors associated with vehicle weight, the potential benefits of weight reduction enable downsizing the engine and energy storage systems, with corresponding cost and/or performance benefits.[364] Alternatively, lightweighting can maximize the vehicle payload to increase fuel-efficiency (see Sec. 2.9.4). NHTSA-sponsored Volpe Center studies of the crash safety performance of future plastics and composite intensive vehicles (PCIV) evaluated the potential safety benefits and remaining research needs of plastics and composites applications in emerging lighter weight, more fuel efficient, and environmentally friendly vehicles.[365]

Aluminum is a mature material that can provide 40 percent weight reduction compared to steel. Advanced high-strength steel (AHSS) can provide weight savings of up to 25 percent over conventional steel. First generation AHSS is already finding applications throughout the heavy-duty vehicle industries. One downside is that AHSS still has some of the corrosion issues of conventional steel.[366]

A variety of even more lightweight and corrosion-resistant composite materials is in MD/HDV production. Fiberglass has a useful lifetime of 20-plus years. Plastic composites also provide significant weight reduction, while carbon fiber achieves the highest weight savings: 40- to 50-percent lighter than fiber-composite. Carbon fiber reinforced composite (CFRP) is extremely strong, durable, and has no corrosion concerns, but comes at a high cost of production and long processing time, which could slow adoption rate.[367] Typically, a core material such as foam core is encased in a fiberglass shell and other reinforced CFRP configurations to ensure structural strength in a crash.

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[363]CalStart. 2012b. Leading Fleets Take Delivery of World's First Commercially Available Hybrid Hydraulic Parcel Delivery Trucks – "Hybrids Without Batteries" www.calstart.org/news_and_publications/CALSTART-in-the-news/CALSTART-Press-Releases/worlds-first-hybrid-hydraulic-delivery-trucks.aspx DOE VTP materials Technologies: Goals, Strategies and Top Accomplishments at www1.eere.energy.gov/vehiclesandfuels/pdfs/materials_tech_goals.pdf

[364] Oak Ridge National Laboratory. 2012. Oak Ridge National Lab Lightweight Materials Program web.ornl.gov/sci/lightmat/Lightweight.html

[365] "Characterizing And Enhancing The Safety Of Future Plastic And Composite Intensive Vehicles (PCIVs)," 2009, A. Brecher, J. Brewer, S. Summers, and S. Patel at www-nrd.nhtsa.dot.gov/pdf/esv/esv21/09-0316.pdf

[366] DOE. 2012. Energy Department Investments to Develop Lighter, Stronger Materials for Greater Vehicle Fuel Economy www.doe.gov/articles/energy-department-investments-develop-lighter-stronger-materials-greater-vehicle-fuel, Lyden, S. 2012. It's a Lightweight Material World www.worktruckonline.com/channel/vehicle-research/article/story/2012/01/it-s-a-lightweight-material-world.aspx?prestitial=1

[367] Lyden, S. 2012. It's a Lightweight Material World www.worktruckonline.com/channel/vehicle-research/article/story/2012/01/it-s-a-lightweight-material-world.aspx?prestitial=1

2.9.1 Penetration/Adoption

Consumer preferences have limited the downsizing options available to vehicle manufacturers, and safety and performance standards have resulted in a very limited ability to reduce weight further with conventional materials.[368] However, there are a growing number of lightweighting cases in MD/HDV fleets, especially in transit buses.

In 2003, North American Bus Industries began manufacturing a 45-foot transit bus with a light-weight all-composite body, called the Compo Bus. Approximately 400 were manufactured between 2004 and 2008, and the largest fleet is in Los Angeles. Some of them have now been in service for more than 10 years and continue to operate. Mobile Energy Solutions LLC introduced a lightweighted transit bus in 2007 with an all-composite body featuring a fuel cell/hybrid electric propulsion system.[369] In 2009, Proterra debuted a lightweighted fast-charge battery electric composite bus, using a light yet durable fiberglass-balsa wood composite. The EcoRide BE35 buses, now operating in several U.S. cities, have a reduced composite body weight of 20-40 percent over a conventional steel or aluminum bus, is climate resistant, and could provide up to a 600 percent improvement in fuel economy based on FTA testing at Altoona due to their combination of lightweighting, regenerative braking, and electric power source.[370]

UPS tested prototype diesel-fueled delivery trucks with lightweight bodied constructed of a plastic resin material instead of steel. The lightweighted trucks achieved a 40 percent increase in fuel efficiency largely due to the truck's 10 percent weight reduction, the advanced powertrain technology, and a more aerodynamic design. The body uses high-impact plastic for the lower cladding and one-piece plastic molded roof. With a payload capacity that is only 10 percent (700 lb.) less than the company's standard delivery truck, the 150-horsepower trucks ran on an Isuzu four-cylinder diesel engine. The lightweighted trucks were successfully field tested in extreme weather conditions over the course of one year, after which UPS ordered 150 of these trucks to run on high-mileage routes.[371]

To date, carbon fiber has been an enabling technology for the composite body of the Proterra bus, and the fuel cells in advanced Van Hool fuel cell buses,[372] but could also become a broadly adopted material in the future if its fabrication costs and volume issues were resolved.

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[368] Oak Ridge National Laboratory. 2012. Oak Ridge National Lab Lightweight Materials Program web.ornl.gov/sci/lightmat/Lightweight.html

[369] Composites World. 2007. New hybrid electric bus takes advantage of composites www.compositesworld.com/articles/new-hybrid-electric-bus-takes-advantage-of-composites

[370] Proterra Inc. 2009. Proterra Brings Future of Green Commercial Transit to California Cities With Zero Emission Clean Bus Tour www.prweb.com/releases/2009/02/prweb1968224.htm; see also www.proterra.com/index.php/products/productDetail/C29/ and www.proterra.com/product-tech/durability-reliability/composite-body/

[371] Kaye, L. 2012. UPS Rolls Out Lightweight Composite Trucks In a Move Towards Energy Efficiency www.triplepundit.com/2012/06/ups-composite-trucks-energy-efficiency/

[372] See Regional Buses Boos CFRP in Alternative Energy at www.compositesworld.com/articles/regional-buses-boost-cfrp-in-alternative-energy; and Proterra at www.proterra.com/index.php/products/productDetail/C32/

2.9.2 Benefits

The Department of Energy launched new initiatives in 2012 for further reducing vehicle weight to improve fuel efficiency.[373] Lightweighting can also mean a reduction in maintenance costs because a lighter vehicle body requires less brake power to stop and may cause less wear on tires and brakes.[374]

Reduction in MD/HDV mass will reduce crash forces to other vehicles, although this effect is likely to be small for light-duty vehicles since truck lightweighting will have only a small effect on the mass differential. This benefit may be canceled out further by the fact that light-duty vehicles are also undergoing lightweighting.

Replacing cast iron and traditional steel components with lightweight materials—including advanced high-strength steel, magnesium, aluminum, and carbon fiber composites — can allow vehicle manufacturers to include additional safety devices, integrated electronic systems, and emissions control equipment on vehicles without increasing their weight. In this way, advanced lightweight materials promise to enhance vehicle safety and performance of vehicles, while boosting fuel economy.[375]

As with most FE technologies, individual payback and economic benefits will depend on the vehicle class and drive cycle. Vehicles that travel long distances and those with high kinetic intensity (e.g., transit buses) stand to benefit the most from lightweighting.[376]

2.9.3 Safety Considerations

In all cases, the safety and crashworthiness of lighter weight vehicles is a significant consideration, as well as other environmental health and safety issues associated with new materials and process technology.[377]

The predominant grade aluminum for body manufacturing loses 80-percent of its strength when welded, so it may not be a suitable material for work trucks with a long service cycle. For fiberglass composite materials, it is important to correctly mount accessories. Concentrated loads at the point of attachment may result in damage of a fiberglass panel. The downside of some plastic composites may include their susceptibility to heat, degradation, and brittleness and over

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[373] See www.doe.gov/articles/energy-department-investments-develop-lighter-stronger-materials-greater-vehicle-fuel and http://energy.gov/articles/obama-administration-announces-142-million-new-funding-develop-lightweight-materials

[374] Lyden, S. 2012. It's a Lightweight Material World www.worktruckonline.com/channel/vehicle-research/article/story/2012/01/it-s-a-lightweight-material-world.aspx?prestitial=1

[375] DOE. 2012. Energy Department Investments to Develop Lighter, Stronger Materials for Greater Vehicle Fuel Economy www.doe.gov/articles/energy-department-investments-develop-lighter-stronger-materials-greater-vehicle-fuel

[376] Lyden, S. 2012. It's a Lightweight Material World www.worktruckonline.com/channel/vehicle-research/article/story/2012/01/it-s-a-lightweight-material-world.aspx?prestitial=1

[377] Quintiere, J. G., Walters, R. N., & Crowley, S. 2007. Flammability Properties of Aircraft Carbon-Fiber Structural Composite www.fire.tc.faa.gov/pdf/07-57.pdf

time when exposed to UV radiation from sunlight.[378] However, thermoplastics resistant to UV and weathering have been developed,[379] and no examples of such lightweight material failures on MD/HDVs were identified in the literature. The use of composites, aluminum, and fiberglass may result in less protection to truck drivers in crashes because of lower crush strength, but no studies or work with significant results were identified. The FAA has sponsored and evaluated fire-safe polymers and polymer composites[380] and examined the flammability properties of carbon fiber composites for structural applications.[381]

2.9.4 Findings and Conclusions

No safety incidents involving or attributable to lightweighting of MD/HDVs were identified in the literature. The fuel economy benefits of reducing vehicle weight have been clearly demonstrated over the past few years in operational fleet pilots and all-composite buses in transit fleets. Lightweighting vehicles may make it possible to install additional safety or environmental equipment on MD/HDVs to further improve their performance. Moreover, rightsizing vehicle payloads, i.e., increasing payload per vehicle as a result of lightweight body materials, could enable reductions in the total truck fleet size, reduced VMT, and a proportional reduction in crashes.[382] NHTSA sponsored research on the crash safety of Plastic and Composite Intensive Vehicles (PCIVs) identified progress in and research needs for characterizing and enhancing the safety of automotive lightweighting composites in structural applications.[383]

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378 Lyden, S. 2012. It's a Lightweight Material World www.worktruckonline.com/channel/vehicle-research/article/story/2012/01/it-s-a-lightweight-material-world.aspx?prestitial=1

379 See www.dotmar.com.au/uv-resistance.html

380 See "Fire safe polymers and polymer composites," 2004, FAA report at www.fire.tc.faa.gov/pdf/04-11.pdf

381 See "Flammability properties of aircraft carbon fiber structural composites," 2007 at www.fire.tc.faa.gov/pdf/07-57.pdf

382 Lyden, S. 2012. It's a Lightweight Material World www.worktruckonline.com/channel/vehicle-research/article/story/2012/01/it-s-a-lightweight-material-world.aspx?prestitial=1

383 A. Brecher et al, "Characterizing and enhancing the safety of future PCIVs," ESV-21 paper 09-0316, at www-nrd.nhtsa.dot.gov/pdf/esv/esv21/Track%2025%20Oral.pdf

3 SUMMARY OF SUBJECT MATTER EXPERT INPUTS ON MD/HD SAFETY IMPACTS OF FE TECHNOLOGIES

3.1 Introduction: Respondents and Fleet Profiles

To obtain primary experience information on safety benefits or disbenefits, interviews[384] were conducted with managers of several large "green" and diverse corporate truck fleets and with managers of public transit fleets with significant fuel efficiency technology adoption. These fleets were selected based on published reports on green technology fleet adoption[385] and are the same large "green" fleets that were analyzed for safety performance relative to conventional fleets in our queries of CSA and FARS databases. In addition, technical experts from medium/heavy-duty vehicle FE-related OEMs, suppliers, and integrators, as well as FE experts from Government agencies were interviewed. The results represent the viewpoints of each interviewee and do not represent the views of their organization or the U.S. Department of Transportation.

Table 3-1 lists the organizations of the subject matter experts who were interviewed**.**

Table 3-1: Broad Cross-Section of Subject Matter Experts Interviewed

Corporate fleets	Public transit	Industry	Government
Coca Cola Enterprises	Houston METRO	EATON Corporation	Argonne & National Renewable Energy Laboratories
Frito Lay	Long Beach Transit	Vanner, Inc.	FMCSA
Verizon Communications	Santa Barbara Metropolitan Transit District (SBMTD)	Parker Hannifin Corporation	EPA SmartWay
ARAMARK	Washington DC Metropolitan Area Transit Authority (WMATA), or Metrobus system	BAE Systems	CALSTART
DHL/Exel		Daimler Trucks North America (DTNA)	DOE Clean Cities Program

The private and public green fleet managers who were interviewed spanned a wide range of MD/HD vehicle types, FE technologies, geographic locations, types of services, and typical drive cycles. These major fleets are among those that have joined the DOE National Clean Fleets Partnership.[386]

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[384] The oral communications with fleet managers were non-standardized, and varied on subject matter depending on the fleet type (such as public transit or government).
[385] See www1.eere.energy.gov/cleancities/national_partnership.html for fleet list See www1.eere.energy.gov/cleancities/national_partnership.html for fleet list
[386] Ibid.

The **Coca Cola Enterprises** fleet includes 15,000 MD/HDVs total; 10,000 are Class 7 or 8. Most of the fleet operates short distance trips, with fewer than 500 tractors driving long distances. Since 2007, the fleet has included 760 hybrid-electric trucks (representing a small vehicle fraction of about 5%), 2 LNG and 5 CNG trucks acquired 1.5 years ago, 8 fully electric Smith Newtons acquired two years ago (GVW 19,000 lbs.), and six Navistar E-star electric trucks (GVW 14,000 lbs.) acquired one year ago. Coca Cola Enterprises has also adopted idle reduction in all of its vehicles, speed governors, and telematics packages, along with a driver-training program to ensure eco-driving and fuel savings.

Frito Lay has about 22,000 fleet vehicles, excluding trailers. The fleet includes 1,200 Class 8 over-the-road tractors, 4,000 trailers, and a delivery fleet of 4,000 straight box trucks. The fleet has reduced its fuel consumption by 14 percent in the past four years despite a concurrent 3 percent growth in goods volume. Frito Lay has set a corporate sustainability goal of 50 percent fuel burn reduction by 2020. It will deploy 275 electric trucks by the end of 2012 and become the largest domestic commercial fleet of all-electric trucks. The entire fleet has broadly implemented idle reduction since the late 1990s, aerodynamic technologies program for its trailers since 2007-08, as well as speed limiters and required driver training. About 70 CNG tractors are also being deployed in 2012.

The **Verizon Communications** fleet, consisting of the Telecom, Wireless, and Enterprise divisions, has 6,000 MD/HDVs. The fleet-wide fuel efficiency average is 11 mpg (c.f. typical HD truck fleet average of 5.7 mpg). A large fraction of the MD/HDV diesels are equipped with 5-minute idle reduction. Though there are no alternative-fueled MD/HDVs, the fleet includes 15 hybrid and 10 CNG light aerials (up to 30 ft. reach booms). The earliest hybrids are from 2008-09, with most hybrids and the CNGs online since 2010.

Aramark's Food and Facilities division fleet is piloting five MD hybrid gasoline-electric Azure Dynamics conversions of 14,000 lbs. GVW E-450s. Eight propane-powered vehicles are in service, though not currently fueled on site, and the fleet plans to deploy new Smith electric trucks soon. A multi-stop urban duty cycle is typical of Aramark vehicle fleet operation. Several different telematics pilot program are underway.

DHL Supply Chain Unit's fleet provides point-to-point delivery of heavy loads, with 1,100 Class 7-8 tractors in the United States, but no alternative fuels are currently in use. "Teardrop" aerodynamic trailers have been use in the U.K. fleet, but not in the United States The fleet duty cycle includes a mix of highway and urban driving. Speed limiters have been universally adopted for several years. DHL has also been conducting a telematics and driver coaching studies on 150 box trucks (under 26,000 lbs.).

Houston Metro (Metropolitan Transit Authority of Harris County) has operated 350 hybrid-electric buses, with 122 parallel hybrid-electric buses first deployed in 2007. Commuter buses travel mostly on the expressway, with little or no urban driving, while other city routes have more stops. More recently, 130 series hybrid-electric buses have been deployed, although the majority of the fleet remains diesel. The Houston transit bus fleet has gained experience with both lithium ion and nickel metal hydride batteries.

Long Beach Transit (LBT) operates 87 gasoline electric series hybrid buses out of a fleet of 247 buses, with hybrids in service since 2007. LBT maintenance and operations staff has had 5 years and more than 11 million hours of service with the hybrid electric buses, which use either ultracapacitors or batteries. 64 Gillig Corp. CNG buses were also rolled out in 2012, fitted with CNG tanks in rooftop compartments.

The **Santa Barbara Municipal Transit District** (SBMTD) has operated and maintained for 20 years a fleet of electric 22-foot shuttle buses from Ebus, with a daily range of 60-75 mi between charges. Ten other electric buses from different manufacturers were tested, but withdrawn from service. Currently, the fleet of 108 buses consists of the 20 electrics; 18 diesel electric parallel hybrids (Gillig, with Allison drivetrains); and the rest diesel. SBMTD has experience with all battery types for energy storage: lead acid, lithium ion, and nickel cadmium batteries. To save on battery energy and extend range, the SBMTD electric buses have no hotel loads or auxiliary power drains and all HVAC needs are met by opening or closing the bus windows.

The **Washington Metropolitan Area Transit Authority** (WMATA) has operated New Flyer hybrid electric buses with Allison parallel drivetrains since 2006, including standard 40 foot and longer articulated models. The number of hybrid electric buses is approximately 400 out of a total bus fleet of 1,500. WMATA has also been operating over 300 CNG buses since 2002.

Although not interviewed, the Los Angeles Metro has safely operated CNG buses for over two decades: it completely converted its transit bus fleet to CNG in 2011, and currently operating over 2,200 CNG buses.[387] Similarly, the New York City Metro Transit Authority (NYMTA) has safely operated a large fleet of New Flyer CNG buses, ordering in 2010 475 new buses in addition to 190 older CNG buses.[388]

3.2 Fuel Efficiency Technology Clusters and Safety Concerns Reported

A theme that emerged from interviews with the SMEs is that fuel efficiency technologies were often introduced into fleets as synergistic “clusters.” For example, intelligent transportation systems (ITS), GPS vehicle tracking, and route optimization were frequently implemented together. Automatic stop-start and other idle reduction technologies were typically bundled with driver training. Hybridized or electric drivetrains typically incorporate regenerative brake technology. As pointed out by a number of SMEs, combining complementary technologies and driver training is important to obtain maximum FE, environmental, and economic benefits.

3.2.1 Alternative Clean Fuels

One corporate fleet manager reported that the only problem with their CNG tractors was a cylinder liner issue that was not specific to the CNG propulsion. It was not a significant safety hazard.

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[387] See “Diesel era ends for MTA buses” 2011 at http://articles.latimes.com/2011/jan/13/local/la-me-buses-20110112

[388] See http://energy-vision.org/new-york-citys-mta-upgrades-its-cng-bus-fleet/

Another corporate fleet with CNG trucks in service since 2010 reported no safety incidents related directly to FE technologies. This fleet has experienced the same accident rates across its FE and conventional vehicles. Even though employees usually blamed any accidents on the truck equipment, they did not blame deployed FE technologies, such as hybrid, CNG, and idle reduction. While he did not report any first-hand safety incidents, the fleet manager was very skeptical of CNG vehicles due to concerns about the safety of high pressure (4000 psi) CNG cylinders potentially exploding in a crash scenario or if ruptured. He also pointed out that shared gaseous/liquid fueling garages are spark- protected at ground level, but not necessarily at ceiling level where natural gas would rise and create the potential for ignition. Particularly in diesel garages that only serve a few CNG vehicles, and especially in cold climates, he stated that best practices and engineering controls for safe ventilation are important. He related anecdotal reports that more people were hurt by opening high pressure CNG lines than by electric shock, e.g., from batteries and high voltage wiring in electric hybrids.

The fleet manager of a third corporate fleet believed that propane is as safe as or safer than gasoline, based on personal experience filling propane vehicles. This manager reported no safety issues with the company's propane or hybrid gasoline-electric trucks. Though he did not perceive any safety issues with alternative clean fuels, he recommended "better public education about fuels like CNG" so that potential adopters "would not be scared."

Engineers at a major truck OEM alluded to the general safety risk arising from multiple small suppliers that implement components downstream without performing extensive tests, owing to the low volumes of retrofitting or producing alternative fuel vehicles. They related an incident in which a supplier began fitting natural gas engines onto one of this company's truck models, but incompatibilities led to overheating and brake fade. This was only discovered after several vehicles had been sold. The engineers said that the risk associated with the high number of configurations and low volumes of alternative fuel vehicle production also applies to the OEMs. HD vehicles are a mix of components from many different suppliers, and unlike commoditized light-duty vehicles there are not generally the engineering resources to system-test, integrate, and model all potential configurations. The engineers noted that there have not been any significant safety problems to date, other than the NG engine retrofit problem.

A U.S. Government official stated that as the first generation of CNG tanks nears the end of their 15-year service life, there is concern within the MD/HDV OEM and engine industry that some expired tanks will not be properly disposed. He reported the case of a salvage yard operator who mishandled the CNG tanks on a vehicle and caused them to rocket into a nearby building. He added that conventional automotive technicians may have the skills or knowledge to deal with natural gas fuel systems. Often NGVs have been unsafely returned to service after a collision without proper inspection for fuel system damage. These defective or weakened NG tanks have resulted in fatal or injurious explosions when they were filled. The official also stated that enforcement of the Federal Motor Vehicle Safety Standard (FMVSS) 304[389] end-of-service replacement provisions for CNG tanks would be critical to make sure that expired tanks are not

[389] NHTSA. 2009. FMVSS 304 CNG fuel container integrity www.nhtsa.gov/DOT/NHTSA/NVS/Crashworthiness/Alternative%20Energy%20Vehicle%20Systems%20Safety%20Research/811150.pdf

unscrupulously re-sold, which could result in similar safety incidents.[390] Concerning the indoor servicing of CNG vehicles, he was aware of one case in which an NGV was operated in a shop in the presence of an active flame heater that led to an explosion.

3.2.2 Drivetrain Hybridization and Electrification Safety

One corporate fleet manager reported that heavy-duty hybrid electric tractors achieved an actual 13-22 percent fuel efficiency FE gain compared to ICE tractors. The fleet manager at this company was very satisfied with their alternative fuel medium- and heavy-duty vehicles' operation and maintenance safety. The manager's main concern was about the too-short (5-year) battery life on the hybrids, as in his experience batteries are dying faster than expected and are expensive to replace. This fleet manager found that some drivers refused to drive the non-air-conditioned E-Star electric trucks in the summer. However, there were no safety issues for EVs related to hot weather. Indeed, both the E-Stars and the Smith electric trucks were reported as "fairly reliable" in high summer heat. Technician safety training was identified as a need for the potential high voltage hazards involved in servicing hybrid and electric vehicles, but he stressed that there have been neither electrocution incidents nor close calls.

Although electric motors have more torque at low speeds than ICEs, a corporate fleet operating Smith Newton electric trucks (E-trucks) found that they do not accelerate faster than ICE trucks, due to programming that prevents breaking of traction. The reliability and availability of the Smiths was also measured as about 300 days meantime between failures (MTBF), which is 50 percent better than the MTBF of ICE trucks. The only potential concern for E-trucks is their limited all-electric range of 50-65 miles, which could become a safety issue if it were stranded in traffic. In addition, while the maximum vehicle speed is 55 mph; going uphill could be limited to lower speeds. Therefore, each E-truck route must be "certified" for safe operation to prevent stranding. With this best practice and driver training, the company has never experienced a stranded E- truck, except for one case in very cold weather.

In one private fleet, no safety issues were reported with regard to gasoline-electric hybrid truck conversions. The manager said that they have experienced 35 percent FE savings and that the hybrid conversions have been "beneficial overall."

A major manufacturer of parallel hybrid drivetrains pointed to the extensive incident-free history of its hybrid electric MD/HDVs (6,000 vehicles over 300 million miles) as evidence of HEV safety for the past five years. The company engineers stated that the rechargeable energy storage system undergoes multiple safety tests and is designed with fail-safes for various misuse and abuse scenarios. Rogue acceleration is prevented through error checking in the hybrid control unit, and less wear and tear on brakes in the hybrid vehicles may lead to improved brake safety by reducing brake fade.

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[390] American Trucking Association. 2009. Expanding ATA's Safety Agenda Executive Summary www.truckline.com/Newsroom/Policy%20Papers/Safety%20Task%20Force%20Report.pdf; Natural Gas Vehicle Owner Community. 2011. CNG tanks never expire? http://cngchat.com/forum/archive/index.php/t-7264.html Review of Limited Calendar Service Life for ANSI NGV2/FMVSS 304 CNG Fuel Containers, Aug. 14, 2012 at www.cleanvehicle.org/technology/CVEFLimitedLifeRationaleR3.pdf

The weights of parallel hybrid vehicles are similar to those of conventional counterparts, so their handling is similar, according to these engineers. What may be a safety risk is the highly variable integration of hybrid components downstream by bodybuilders: the case was recalled of an operator being stranded in a bucket without power. Better standardization, knowledge sharing, or new best practices may be needed in the future to ensure operational safety. Another potential safety concern is the uncertain battery lifetime due to variability of climate and duty-cycles. Without state-of-charge indicators, this could conceivably leave vehicles underpowered or stranded if the battery degrades, and is not serviced or replaced in a timely manner. The engineers noted that HEVs and EVs share the same potential battery-related safety issues and required safeguards and best-practices in prevention and maintenance.

Another hybrid-electric drivetrain company expert concurred that its 3,800 series hybrid electric buses (HEB) in operation around the world had a long and mostly incident-free history. This chief engineer pointed out that minimal vehicle chassis changes are needed, and that the vehicle handling is deliberately similar to a conventional bus. Multiple fail-safes are designed against electrocution, and the engineer stated that the bus's quieter operation is not a detectability hazard to other road users. The engineer stated that the breakdown rate of hybrid electric buses is not any higher than that of ICE buses. Moreover, a hybrid bus is still able to pull off the road when there is a failure with the ICE or its electric motor, and this feature has been used in service. At the same time, though, a battery cooling system failure had to be addressed through engineering redesign, suggesting the need to evaluate best practices for preventing damage to new FE subsystems that may not be compatible with existing protocols—in this case, pressure washing of the vehicle that short circuited the ESS.

The operations manager of a transit agency that has used hybrid diesel-electric buses with two different drivetrains since 2007 reported occasional early safety issues with over-speeding of the traction motor; when this occurred, the bus entered a creep mode and had to be taken out of service. There was an instance of an operator who tried to keep the traction motor working in creep mode, shorted out the plate, and caused hydraulic fluid to leak down the bus. This failure mode only happened once on one of the hybrid drivetrain types operated by the transit agency. A recommended countermeasure was better operator training to deal with emergencies on hybrid buses and to understand their failure modes.

Another transit agency operations manager reported that their HEBs did not fully deliver the promised FE gains, but that they had brought a 90 percent decrease in brake maintenance costs versus diesel buses. The ultracapacitors used as the energy storage system on some of the buses developed an acetonitrile electrolyte leak that had to be fixed under warranty. The mean time between road calls for hybrid buses at this agency was comparable to diesel: 9,000 versus 11,000 hours.

The electric buses (EBs) operated by an urban transit agency have had no safety issues, but they have had service interruptions, according to the fleet manager, which mainly involved older lead acid batteries. Newer lithium ion batteries used by the fleet have been far more reliable. When the hybrid electric buses occasionally break down while in service, they have to be towed to the central depot. However, experience with HEB/EBs shows that their brakes last longer than the brakes of diesel buses. The fleet manager said that the agency's experience with electric and hybrid buses has been positive overall and that they are very popular with users.

Regarding hybrid hydraulic vehicles (HHVs), an engineer with a major drivetrain manufacturer stated that the basic technology used in these drivetrains is proven technology, with many decades of engineering knowledge. He stated that the company's HHV drivetrains are designed for the 10-year lifetime of a heavy-duty truck. Also, there are no safety issues associated with the mass transfer of hydraulic fluid between accumulators, and multiple redundancies exist against rogue vehicle movement commands. His chief recommendation was for continued improvement of vehicle part integration to prevent any possibility of conflicting system signals.

Hydraulic hybrid drivetrains have similar failure modes to existing hydraulic systems on MD/HDVs , i.e., leaks. Due to the high fluid pressure (5,800 psi), a leak can lead to high-velocity fluid ejection that could cause potential injury to bystanders. There is always a risk of vehicle stranding due to leaks and loss of propulsion. Several of these types of strandings were reported by another HHV drivetrain manufacturer. At the same time, the anti-lock brake system (ABS) friction brakes on HHVs provide a backup in case the hydraulic system fails, ensuring safe stopping capability. The fact that the friction brakes are cool may also improve their stopping performance, a safety benefit. The engineer stated that acceleration of the HHV is not unsafely quiet, and that drivers report they like operating the HHVs. Although the engineer did not have data, he suggested that it is possible that the extra 1,700 pounds of weight added by a series HHV drivetrain may affect the braking distance and handling of the truck. Maintenance best practices implementation in an HHV fleet is considered safety-critical to and includes regular inspection of hydraulic hoses, oil, and accumulators to detect and address leaks.

3.2.3 Intelligent Transportation Systems and Telematics

The manager of one corporate fleet reported that since installing both auto start-stop and telematics for monitoring of vehicle operation on all their vehicles two years ago, the fraction of unproductive engine operating time has decreased from 30 percent to 9 percent. He added that no safety incidents were documented in the fleet for this cluster of FE technologies.

Another company that had outfitted 80 percent of its fleet with GPS and telematics that monitor FE reported that out-of-route miles, acceleration, and congregation events (when drivers use their trucks to meet and socialize during work hours), decreased 10 percent under engineered route lengths, compared to 20-30 percent over engineered route lengths prior to having training and installing telematics. Hence, the use of telematics on vehicles has led to a reduction in vehicles miles traveled VMT, which likely led to fewer crashes. The fleet manager of this company also believed that efficient drivers are safer drivers, though the company did not yet have data to quantify this.

3.2.4 Speed Limiters

Two corporate fleet managers both stated that 65-mph speed limiters have been universally in place on all their respective vehicles since the late 1990s, with no resulting safety issues reported. One fleet manager believed that speed-limiter-related safety concerns could only be encountered when trucks pass other vehicles on the highway instead of staying in the right-hand lane behind other vehicles as suggested. He recommended combining speed limiters and driver training programs to improve truck safety.

3.2.5 Idle Reduction (Auto Stop-Start)[391]

Idle reducing auto start-stop was implemented on nearly the entire fleet of a major company about 15 years ago. Although the resulting FE gain is difficult to measure, there have been no safety-related concerns.

Although FE gain data is operationally difficult to measure at one company with broad idle reduction adoption, there have been no safety issues with the engine shut-off feature. No employees have blamed any mishaps on the idle reduction feature.

A truck auxiliary power supplier and integrator stated that idle reduction technology and electric auxiliary power systems in aerial work trucks have shown no known safety issues. According to the engineer, the proof that the system is working seamlessly is that drivers don't realize the system is ever turning the engine on and off to recharge the vehicle batteries. He cited a test of the system on 22 aerial trucks in Montreal that demonstrated 16-30 percent FE gains. The utility company testing the system enforced idle reduction by cutting off power to work systems whenever the engine was on, so drivers were unable to cheat.

One U.S. Government idle reduction program leader/coordinator stated that in 10 years she has seen no safety incidents or issues due to idle reduction equipment. If there had been any serious safety concern, this researcher believed it would have shown up. In an extreme temperature scenario when a vehicle engine auto-stops and then has to restart, the auto-start would usually be run by an APU not linked to the rest of the motor system; the researcher did not believe that auto stop-start could cause a breakdown on the highway or at a stoplight, which are the failure scenarios that could potentially cause a crash or congestion.

3.2.6 Driver Training: Human Factors and Operation Issues

One of the corporate green fleets partnered with two outside companies to implement a comprehensive driver-education program focused on FE techniques: anticipation, coasting**,** eliminating unnecessary idling, keeping momentum, and keeping distance. Eco-driving "rodeos" are also held to train drivers.

Another corporate fleet manager stated that he is confident that "fuel efficient driving is safe driving" and vice versa. His company has committed to train all of its drivers and reports that all trained over-the-road drivers have achieved a 6-20 percent FE improvement. As a general observation, the fleet manager stated that when deciding on fuel efficiency technology implementation, "Fleets don't necessarily consider the safety impact unless there is a negative risk when picking a fuel efficiency technology, or unless there is good data on the positive safety impact of the FE solutions."

LCVs were supported by one of the corporate fleets as a fuel efficient way to transport low weight cargo. The corporate fleet SME interviewed stated that he "could not think of a single road safety incident involving LCVs in the western United States." This anecdotal view was

[391] The North American Council for Freight Efficiency (NACFE) 2012 study on idle reduction early adoption costs and benefits at http://nacfe.org/wp-content/uploads/2012/07/NACFE-2012-Anti-Idling-Study-062812.pdf

supported by engineers at a truck OEM, although they added that the longer stopping distance of heavier LCVs is a potential safety disbenefit.

One large corporate green fleet has deployed a telematics driver-monitoring system called SmartDrive[392] on 150 box trucks and combined this technology (which has internal cameras to monitor texting, distractions, and about 70 other "driving defects") with daily driver coaching. Monitoring and recording of driver behavior, combined with coaching, has reduced distracted and aggressive driving and provided significant FE and safety benefits. Since implementation, the mean distance between driver defects such as texting and hard braking has doubled to 600 miles from 300 miles. This fleet manager believes that technological solutions and driver coaching should occur in tandem for maximum FE and safety benefit, and he believes that driver training is the more critical element of the two. He agreed that there is evidence of telematics alone decreasing unsafe behavior. His company in the UK-implemented GreenRoad[393] for on-board behavioral feedback found it reduced "driver defects" by 75 percent on 15 test vehicles.

3.2.7 Tire Systems: Wide Base,[394] LRR,[395] and TPMS[396] Safety Issues

Wide base tires were considered for use by one corporate green fleet manager, who recognized some benefits, but was concerned that if a tire blowout occurs there is no redundancy. This lack of redundancy was considered a potential safety hazard of wide base tires. However, a mechanic at the same company stated that he had never experienced any problems with the wide base tires installed on the two tractors and 14 trailers within the fleet. Other concerns articulated were not safety-related, e.g., the tires are "very expensive" and so far have poor availability.

Another corporate fleet manager reported that he installed a TPMS without real payoff, because the TPMS flaw detection was not early enough to prevent tire damage. This fleet manager believed that TPMS is unlikely to prevent blowouts, when compared to monthly yard checks of tires. At the same time, his parent company has been running wide base tires for some years now, but it is not yet clear if these tires have produced notable FE gains.

Engineers at one truck OEM stated that they were unsure why super-single tires are not catching on despite the technology's proven FE benefit. They believed that the slow adoption of single tires—and of other FE technologies, for that matter—is probably not due to degraded safety performance, but rather due to fears of increased downtime, specifically for tires. The perception is that the downtime for single tires is twice as high as for duals. This would therefore be a reliability issue and not a safety issue.

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[392] SmartDrive Systems. 212. SmartDrive www.smartdrive.net/

[393] California Natural Gas Vehicle Coalition. 2012. Cummins Plans 15-Liter HD Engine www.cngvc.org/pdf/newsletters/CalNGVNews_041612.pdf

[394] See EPA SmartWay Verified Technologies for fuel efficiency improving tires at www.epa.gov/smartway/forpartners/technology.htm

[395] EPA. 2012. Low Rolling Resistance Tires A Glance at Clean Freight Strategies www.epa.gov/smartway/documents/partnership/trucks/partnership/techsheets-truck/EPA-420-F10-041.pdf

[396] North American Council for Freight Efficiency. 2012c. 2012 Tire Pressure Study http://nacfe.org/wp-content/uploads/2012/07/NACFE-2012-Tire-Pressure-Study-062812.pdf

Without citing specific experience, these engineers suggested that LRR tires could negatively affect truck stopping distance and stability control, a potential safety disbenefit. They stated that LRR tires can make passing NHTSA stability control tests more difficult for vehicles, and they were hesitant to recommend them.

3.2.8 Aerodynamic Components and Safety

An aerodynamic retrofit program for trailers of a green corporate fleet started in 2007. Although the associated FE gain has been difficult to measure, the safety performance of aero components was tested extensively in wet and other driving conditions, including pressure envelope interactions with other vehicles, and crosswinds. Aerodynamic system safety was deemed solid, with no instances of detaching.

A major truck manufacturer has deployed fuel tank fairings, side extenders around sleepers, and over-the-sleeper fairings as part of its high-efficiency line of products for over-the-road trucks. While the engineers had heard concerns about railroad crossings and dock approaches damaging under-trailer skirts, they had never actually observed such problems. They also had no knowledge of any aerodynamic components that have detached from vehicles.

This same manufacturer is currently studying the use of cameras to replace rear view mirrors on over-the-road trucks, which would offer approximately 1 percent FE improvement. The engineers stated that rear-view cameras have the potential to fail and that there are more ways for cameras and displays to fail than for mirrors. According to these engineers, the failure of a rear-view camera is a safety risk comparable to losing a tire, since the vehicle could then no longer legally (or safely) be operated.

These engineers said that an important consideration for aerodynamic components is that drivers are required to regularly inspect their vehicles. Covering underside or other components with aerodynamic fairings can make them harder to inspect; for example, CNG relief valve shrouds, wheel covers, and certain fairings. Drivers and inspectors need to be able to see through wheel covers and to be able to access lug nuts through them. These covers must also be durable to withstand frequent abuse.

While this manufacturer did not offer an active fifth wheel, intended to reduce the cab-trailer gap, the engineers stated that its safety could be ensured through a variety of fail-safe mechanisms, such as ratcheting.

3.2.9 Lightweighting Materials

As discussed in Section 2.9, there are multiple lightweighting materials options for weight reduction of MD/HDVs to improve their fuel efficiency without loss of crashworthiness. These materials include aluminum, fiberglass composites, advanced high-strength steel, plastic, and carbon fiber composites in either structural or internal padding applications. Although light-weighted vehicles offer improved maneuverability and shorter stopping distance, for specific lightweighting materials, they may also result in decreased survivability in vehicle fires. Engineers at one heavy-duty truck OEM suggested that new lightweight materials (such as carbon fiber composites and resin epoxies) are making it harder to fight vehicle fires. They stated that it may take less time for a vehicle to become fully engulfed in fire with more such materials incorporated, although they did not cite any actual experience. These engineers recalled a conference speaker who claimed that when "a lightweight vehicle fire begins at highway speed, it could be too late by the time the vehicle stops."

More potential crashworthiness safety issues related to lightweighting vehicles with plastics and composites were discussed in a 2007 NHTSA/Volpe report and research roadmap.[397]

3.3 Conclusions Regarding Key Safety Issues

Based on the collective input from SMEs and the concerns raised, the perceived potential hazards associated with the adoption of FE technologies by MD/HDVs were summarized. Available countermeasures were also identified, largely based on the SME inputs. The top five FE MD/HDV safety issues by perceived potential hazard were identified as follows, in no order of precedence.

- ***Potential ignition or explosion scenario in shared natural gas and liquid fuel indoor fueling facilities.***
  Since gaseous fuels rise whereas liquid fuel vapors sink, the fire protection requirements for servicing vehicles indoors that use each type of fuel are different. Ignition protection in diesel or gasoline facilities is typically at ground level; natural gas facilities must eliminate ignition sources near the ceiling. Due to the high cost of a dedicated NG fueling facility, some fleets may use shared fueling facilities that service both kinds of vehicles. Robust countermeasures include strictly fueling NGVs in outdoor facilities, if the climate permits, or enforcing strict compliance with NFPA 52 and/or NFPA 57 codes for any facility that serves CNG or LNG vehicles, at any point in time. Engineering controls such as methane detectors, visual/audible alarms, induction-motor HVAC equipment, and other safeguards to prevent ignition in NGV depots are likely to be more effective than relying on process controls, such as manually opening doors or vents whenever an NGV is brought into a shared indoor facility.

- ***Degraded or expired CNG tanks that remain in service are more likely to rupture.***
  The first generation of CNG tanks is reaching the end of its service life. There is no national uniform oversight of their proper decommissioning and destruction. There are reports of expired or damaged CNG tanks being unscrupulously resold through shops and online, e.g., on eBay.[398] FMVSS 304 requires a statement to be placed on the tank by the manufacturer: "This container should be visually inspected after a motor vehicle accident or fire and at least every 36 months or 36,000 miles, whichever comes first, for damage and deterioration." Although FMVSS 304 does not require destruction of the aging CNG tank after 15 years, it does require a statement: "Do Not Use After (manufacturer must insert the month and year that mark the end of the manufacturer's recommended service life for the container)." In addition, NGV training would

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[397] Report No. DOT HS 810 863 "A Safety Roadmap for Future Plastics and Composites Intensive Vehicles," Nov. 2007, at http://volpedb.volpe.dot.gov/outside/owa/vntsc_outside.product_repository.display_item?p_doc_id=30707
[398] What happens when your CNG tanks expire? At www.government-fleet.com/article/print/story/2010/05/what-happens-when-your-cng-tanks-expire.aspx

minimize any safety risk for automotive mechanics who service NGVs to ensure that damaged CNG tanks are not placed back in service without the necessary inspection and/or replacement at end-of-service life.

- ***Flammability of lightweighting materials and toxicity of burning byproducts.***
  The SMEs stated that fiber reinforced composites, such as the carbon reinforced polymers, used in high end and NASCAR racing cars, are more flammable than steel. The fire safety and health hazards of burning composites include the potential release of volatile organic compounds, toxic microscopic fibers, and combustion products. For instance, carbon fiber composites and resin epoxies used in aircraft structural applications are ***more*** flammable and can burn completely, releasing toxic airborne fibers and other byproducts.[399] The SMEs suggested that although the probability of such an event might be low, the consequence could be of medium to high severity and the fire safety and environmental health performance would benefit from further study. Passive fire protection coatings, such as Vermitex, can be integrated to address potential flammability hazard of these materials. Fire safety of light-weighted MD/HDVs could benefit from further study, since both fire performance and burn byproducts toxicity depend on the choice of lightweighting materials and their structural or interior application.
- ***Low-rolling resistance tires may increase stopping distance and degrade stability control.***
  An SME suggested LRR tires could introduce a significant safety concern if they increase stopping distance and degrade stability control. Potential countermeasures to offset a degradation in stopping distance or in stability control include vehicle lightweighting, improving driver training, and reducing vehicle speed limits, e.g., by installing speed limiters.
- ***Incompatible FE components and subsystems.***
  The integration of FE vehicle subsystems has been low production volume, with relatively sparse engineering and validation resources allocated for each vehicle configuration. Although SMEs only cited two concrete examples where this led to safety issues, they suggested that the probability of integrating incompatible components might be medium to high (consistent with the Risk Matrix shown in Figure 5-1), and that the consequences warrant further study. Possible countermeasures include standardizing designs and equipment across manufacturers, and utilizing whole vehicle crash tests and safety certification that account for the entire suite of on-board subsystems. Increased standardization, knowledge sharing, and development of best practices could help to ensure operational safety of FE MD/HDVs.

In addition to the above top five perceived potential safety issues, the SME input revealed several other findings about the impacts of FE technology on safety performance, as well as on

[399] See FAA 2007 report "Flammability properties of aircraft carbon fiber structural composite" at www.fire.tc.faa.gov/pdf/07-57.pdf; and Gandhi FAA article "Post-crash health hazards from burning aircraft composites" at www.aviationfirejournal.com/aviation/library/VOL6-Hazards.pdf

non-safety considerations. For example, multiple SMEs concurred that FE technologies offer benefits beyond fuel cost reduction and environmental compatibility.

These SMEs reported that FE technologies reduced their fleet maintenance costs. This could result from less frequent brake replacements when regenerative braking was incorporated, fewer moving parts in the case of electric drivetrains, or less engine wear in hybrid hydraulics that launch the vehicle from a stop.

SMEs accounts indicated that, although electric and hybrid electric vehicles contain onboard electric propulsion and energy storage systems with high voltages, there have been no significant safety incidents. The probability of electrocution by electric vehicle energy storage systems is low, as long as personnel and first responders are properly trained. Furthermore, additional layers of engineering safeguards to prevent electric shock are continually being added by the OEMs.

In terms of hybrid vehicle operational safety, the requirements for dealing with emergencies such as a disabled hybrid drivetrain MD/HDV can be quite different from those of a diesel truck or bus. Better operator training was recommended by the SMEs to safely and effectively deal with the distinct failure modes of FE technology-equipped vehicles, including proper use of emergency propulsion modes designed to steer a disabled vehicle to the roadside.

The general potential safety concern articulated for HHVs is the high pressure of the fluid system. However, the low number of in-service vehicles means that more time would be necessary to more thoroughly assess their safety performance. In the meantime, robust hydraulic line and accumulator tank inspection and maintenance schedules would minimize any safety risk for the limited existing fleets, as these appear to be the main potential points of failure.

According to the SMEs queried, speed limiters in MD/HDVs have not led to safety issues so far. One SME specifically recommended their adoption in tandem with driver training to improve fleet safety. The only potential safety concern they identified was unsafe passing of other vehicles. Although a suggested countermeasure would be for speed limiter-equipped MD/HDVs to stay in lane and not pass, there are situations where passing at higher speed may be necessary.

Idle reduction technologies such as auto start-stop and auxiliary power units have demonstrated FE benefits of varying levels without any reported safety hazards.

SMEs disagreed on whether there is in fact any effect on safety performance, or only a potential effect on reliability. Further study with a larger sample size of users would provide more information on any potential risks.

Aerodynamic components did not introduce any reported safety issues, although there is potential to interfere with preventative safety if the aerodynamic system makes vehicle components inaccessible for inspection and hazards are not detected in a timely manner. Removable aerodynamic components that can be temporarily detached, folded, or tilted to allow inspection could address these potential secondary safety hazards. For components whose inspection is visual, transparent aerodynamic components (e.g., polycarbonate) is another countermeasure.

4 SCENARIO HAZARD ANALYSIS AND PREVENTION/MITIGATION STRATEGIES

4.1 Technical Approach to Hazard Analysis of FE Technologies and Fuels in MD/HDVs

Technically, the event Risk (R) is defined as the product of a hazardous event probability of occurrence (p) by its consequence severity (C). However, for lack of empirical safety performance data, the classic Risk Assessment Matrix (RAC) shown in Figure 4-1 below is not yet feasible for a safety analysis of specific FE technologies safety impacts. Ideally, a hazard characterization and classic probabilistic hazard analysis of MD/HDV crashes attributable to or involving FE technologies and alternative fuels should be based on ample statistics derived from real world data. However, though several types of FE technologies have been introduced individually or in clusters (e.g., speed limiters, idle reduction, route selection using GPS and ITS) over the past decade, most have been adopted only recently, and have very slowly penetrated truck and bus fleets.

RISK ASSESSMENT MATRIX

SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Figure 4-1: A Summary Risk Assessment Matrix Ranking and Prioritizing Hazards[400]

A best practice for cost-effective risk management is to prioritize the hazard levels by Risk (which is the product of probability and consequence) .[401] This enables appropriate allocation of resources for risk reduction measures to address those high consequence events that result in loss of life, injuries and/or greatest property damage. The Hazard Matrix schematic in Figure 4-2

[400] Source: DOD MIL-STD-882E. See latest update of DOD-MIL-STD-882_E, System Safety Standard Practice, May 2012,at www.system-safety.org/Documents/MIL-STD-882E.pdf

[401] See for instance the ANSI-endorsed standards ISO 27001-Risk Assessment and ISO 31000 (2009) Risk Management- Principles and Guidelines

indicates potential risk mitigation responses (from low to high), based on combinations of event probability and consequence severity. Some risk levels related to vehicle operation can be transferred via insurance coverage; while negligible risks are routinely accepted as the cost of doing business. While there are currently numerous Federal and State laws and incentives for manufacturing and buying fuel-efficient vehicles,[402] there are as yet no auto insurance credits for better safety in operating vehicles with FE technologies that we could identify.

The classic Hazard level ranking matrix in Figure 4-2 shows what types of hazards must be addressed versus those considered too improbable, unaffordable to control, or of negligible impact: most risk categories can be prevented or managed cost effectively through engineered controls, or with design or operational changes. The vertical axis corresponds to the Consequence severity, and the horizontal axis shows the frequency of event occurrence.

	A Frequent	B Probable	C Occasional	D Remote	E Improbable	F Impossible
Catastrophic I	Design action required to eliminate or control hazard 1	Design action required to eliminate or control hazard 2	Design action required to eliminate or control hazard 3	Hazard must be controlled or hazard probability reduced 4	9	12
Critical II	Design action required to eliminate or control hazard 3	Design action required to eliminate or control hazard 4	Hazard must be controlled or hazard probability reduced 6	Hazard control desirable if cost effective 7	Assume will not occur 12	Impossible occurrence 12
Marginal III	Design action required to eliminate or control hazard 5	Hazard must be controlled or hazard probability reduced 6	Hazard control desirable if cost effective 8	Normally not cost effective 10	12	12
Negligible IV	10	11	Negligible hazard 12	12	12	12

Figure 4-2: A Hazard Level Matrix Showing Ranked Event Probability and Consequence Severity.

A preliminary hazard analysis (PHA), a probabilistic fault-tree analysis (FTA), or failure mode and effect analysis (FMEA) all require statistically meaningful information on single-point failures, or failure chain frequency of occurrence, and their respective severity of consequences. At present, the lack of statistical data on crashes attributable to a specific category of FE technology, or a cluster thereof, or to alternative fuel use precludes either quantitative or qualitative hazard characterization and ranking.

The literature review (Chapter 2) and focused interviews conducted with SMEs familiar with fuel efficiency technologies and MD/HDV fleet operations (Chapter 3) have also indicated that

[402] See the DOE Alternative Fuels Data Center laws and Incentives at www.afdc.energy.gov/laws and www.afdc.energy.gov/laws/matrix/tech

there is no statistically meaningful information causally linking crashes to any specific FE technology. Further, the introduction of new vehicle FE technologies and the integration of new or upgraded automotive subsystems (both FE related and unrelated), alternative fuels, and associated refueling infrastructure may lead to as yet unforeseen failure modes and failure chains due to greater complexity and to the "learning curve" period.

The NACFE 2011 Freight Efficiency Technologies Benchmark report[403] has evaluated the rate of adoption over time for six major FE technology clusters by 18 representative truck fleets, as shown in Fig. 2-12. NACFE has also conducted in-depth benchmarking studies of the adoption benefits for specific FE technologies, such as tire pressure monitoring, anti-idling technologies, and 6x4 packages. However, MD/HDV fleet-wide penetration and operational experience with vehicles equipped with FE technologies to date with are still too modest to quantitatively modify the crash safety performance of the national MD/HDV fleet.

Only a few FE equipment failures may be safety-critical, and their identification is only possible through realistic scenario analysis and modeling, and/or through longer-term in-service fleet tests and evaluations, such as those performed by NREL[404] for hybrid electric buses, trucks and delivery vans. Some safety-critical failures may show up after considerable time, after a warranty period or design life ends. Typically, new products may be overdesigned with extra redundancies and safeguards since bad publicity after a major a failure with severe public safety impacts can lead to massive recalls, close a new production line, and potentially bankrupt affected operators and OEMs. The OEM engineers interviewed indicated that they design, build and integrate new FE technology and fuel subsystems into MD/HDVs for safe operability, and that CMV drivers are trained and certified to operate them in a safe manner. Moreover, new fuel efficiency subsystems (e.g. hybrid drive, TPMS, aero-skirts) integrated into commercial vehicles are typically overdesigned to ensure their safe operation for the duration of the design life, and/or warranty coverage.

Furthermore, the NHTSA/FARS and FMCSA/CSA databases do not include detailed information on vehicle FE technology involvement in crash reports. The 2007 FMCSA LTCCS report to Congress[405] showed that the large truck vehicle related relative contributions to crashes are smaller than driver-related crash causes, of which vehicle-related causes represent 10 percent.

At present, no quantitative risk ranking of safety hazards related to FEs and alt-fuels, or even a structured qualitative PHA is possible at present due to:

- The lack of statistical safety data of MD/HDV vehicle crashes linked to FE technologies.
- Insufficient and only short duration experience of SMEs who provided inputs with actual crash or other safety mishaps for "clean fleets."

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403 See NACFE 2011 Benchmarking report and update at http://nacfe.org/wp-content/uploads/2012/09/NACFE-2012-Benchmark-Study-Update-062812.pdf and related in-depth FE technology benchmarking studies and barriers to adoption at http://nacfe.org/

404 See www.nrel.gov/news/press/2012/1987.html and www.nrel.gov/vehiclesandfuels/fleettest/publications_hybrid.html

405 See LTCCS FMCSA report to Congress at www.fmcsa.dot.gov/safety/research-and-analysis/report-congress-large-truck-crash-causation-study

- The lack of statistical confidence to enable ranking potential hazards by probability, consequence and overall risk level;
- Limited and sparse data in cited literature on hazardous incidents due to alternative-fuels operations, and/or fires due to rechargeable Lithium Ion batteries.
- The SMEs consulted offered in Section 3 only limited available information and opinions on potential hazards and their top five safety concerns, based on their own experience with clean commercial MD/HDV fleets, or transit bus fleets.

Credible hazard scenarios can be proposed and analyzed to provide insights into the worst-case consequence. A deterministic scenario-based risk assessment (RA) methodology was adopted, in which a "worst case" scenario and its consequence are assumed, and the potential prevention and mitigation options to reduce impacts (through compliance with safety regulations, applicable voluntary technical standards, or adoption of industry best practice) are explored. Some risk analysts object to this type of deterministic risk assessment because it focuses on worst case scenarios with severe consequences, which are considered to be a rare occurrence. Prevention or mitigation of such "worst case" events is often costly and considered unduly "conservative."[406] Nevertheless, both "best case" and "worst case" scenarios can be used as a tool to bound or scope possible risk levels, and can offer insights into engineered or operational procedures that could prevent or respond to hazards. Given the lack of hard data on highway safety impacts, the hazard scenarios rely on the literature findings and on the SMEs inputs (Chapter 3) based on their limited experience or qualified opinions. Consulting experts for their informed opinions regarding hazard identification and ranking is called the Delphi Approach. News and literature accounts of real crashes and accidents involving CNG trucks and buses, or hybrid and electric vehicles identified through Internet searches and related trade safety information were also used in the detailed scenarios below.

Scenarios involving FE technologies, alternative fuels, and operator factors leading to a vehicle crash, fire, or explosion are illustrated. Each scenario is discussed below in detail in context, and can be supported by at least one reported actual incident, cited literature, or by SMEs inputs. This scenario analysis allows for identification of strategies to prevent and/or mitigate such hazardous occurrences.

4.2 Scenario Analysis of Safety Hazards identified by SMEs

4.2.1 Hazard Analysis of CNG-Fueled Trucks and Buses

Cleaner CNG fueled MD/HDVs have been safely operated in the United States and worldwide since the early 1980s with over 90,000 in use today. Public transit authorities have accumulated considerable experience with the safe operation of large CNG bus fleets over the past two decades, according to APTA[407], such as Los Angeles Metro, which operates the largest (over 2200) urban fleet of CNG transit buses in the United States.

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406 See postings at www.palisade.com/risk/risk_analysis.asp

407 See "Transit on the cutting edge of clean technology," Sept 2012 at www.apta.com/resources/statistics/Documents/Transit-Clean-Technology.pdf

A recent FMCSA safety study of the commercial NGV fleet[408] cited the DOE/EIA 2010 inventory of 43,088 MD/HDV vehicles, including 21,510 urban transit buses, 7,466 heavy-duty trucks, 5,925 medium duty trucks and 8,187 vans. As CNG MD/HDVs are now being rapidly deployed, attention to safe operability and refueling is paramount.

NGV America safety statistics[409] cite the safe and reliable in service operation of over 10,000 CNG fueled transit and school buses and shuttles, stating that 1 in 5 new transit buses are CNG-fueled. An NGV America survey of over 8,331 NGVs showed they have a better crash safety record than conventional counterparts, with a 31 percent lower crash rate, no fatalities and 37 percent fewer injuries. Of only 7 fire incidents noted, only one was due to the CNG fuel system failure. The strong cylinder tank survived intact in crashes, with no leakage or fire due to the automatic fuel release valve activated in case of excessive heat or pressure build-up.

Powertech[410] noted that only 26 CNG cylinder failures occurred from 2000 to 2008, and that the probability of a CNG vehicle cylinder failure is quite low, and that catastrophic ruptures are very rare. The events cited through 2008 (see Figure 2-4 and general discussion above) included: 5 failures due to mechanical damage, 12 due to environmental damage (exposure to temperatures too hot or too cold), 8 leaks due to metal liner and 6 due to plastic liner failures; only 16 resulted in vehicle fires. Aftermarket conversions to CNG using steel (Type 1) cylinders were involved in 50 percent of these failures. The Powertech failure analysis also illustrated how CNG buses with Type 4 composite tanks mounted on the bus roof were damaged in collisions with low overhead barriers or tunnels. In these cases, the punctured tanks released the CNG, but did not burst, explode, nor ignite. Compliance testing with FMVSS 304 has reduced the number of deaths and serious injuries due to CNG leakage from tanks ruptured in crashes.

Given the very few actual incidents either reported by fleet managers (in Chapter 3) or in the literature (Chapter 2), safety hazards due to CNG tank failures in MD/HDVs could not be ranked by probability, consequence, severity, or overall risk level. Only tank failures for CNG-fueled trucks are discussed in this scenario; crashes of CNG tanker trucks delivering fuel to refueling compressor stations or industrial sites are omitted, since they are already subject to compliance with PHMSA hazmat regulations. Greater highway safety risk could potentially result from highways crashes of loaded CNG tanker trucks delivering fuel to refueling stations and compressor mishaps, but no such incidents were found documented in the literature.

4.2.1.1 Incidents of Vehicle Fires or Explosion Due to CNG Tank Rupture

Several SMEs identified the potential for ignition or explosion scenarios due to pressurized (3,500-psi) CNG tank rupture, or to a leak or malfunction of the automated vent on the fuel tank as a risk concern in purchasing and operating CNG fueled trucks. The SMEs conjecture, rather than experience, was that the probability of such an event would be medium, but the

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[408] FMCSA Natural Gas Systems Safety Study, 2012 at http://ntl.bts.gov/lib/51000/51300/51334/Natural-Gas-Systems-Tech-Brief-508.pdf

[409] See "How Safe are Natural Gas Vehicles?" at www.ngvc.org/tech_data/techbulletin2.html

[410] See "CNG and Hydrogen Tank Safety, R&D and Testing," Joe Wong, Powertech Labs, Inc., 12.10.2009, at www1.eere.energy.gov/hydrogenandfuelcells/pdfs/cng_h2_workshop_8_wong.pdf

consequence could be high. Tank failure either could occur due to a road crash, or due to accidental leaks or venting during refueling indoors or outdoors, followed by ignition.

Recent CNG tank failures documented in the literature and internet illustrate potential hazards:

- In February 2011, a CNG explosion at Pierce Transit refueling depot (near Seattle) occurred during a CNG bus refueling (probably due to a compressor failure), destroying the bus.[411]
- In February 2012, in Statesboro, Georgia, a university CNG bus caught fire and exploded when a small spark started a fire that reached the CNG tank, but the driver evacuated all passengers in time. Bus passenger fatalities and/or severe burn injuries could result from such an accident if timely evacuation were not possible. Worse consequences might result if such an event occurred on a busy road at rush hour, causing a multi-vehicle chain of fire or explosions, and causing harm to passengers. According to industry best practices (standard NFPA 52) every CNG cylinder must be equipped with a pressure relief device (PRD) to safely vent the gas in the event of a vehicle fire, thus totally avoiding cylinder rupture. The explosion indicates that the PRD was not present, or malfunctioned. These incidents suggest that both manufacturing standards, and in-use safety standards for vehicle maintenance and condition are needed to ensure that necessary safety systems (i.e., PRD) are in place.

4.2.1.2 Rupture of Degraded or Expired CNG Tanks

NHTSA has been conducting active research on CNG tank failures, to ensure safety under FMVSS 304, "Compressed Natural Gas (CNG) Fuel Container Integrity."[412] FMVSS No. 304 and the ANSI NGV2 standard set minimum performance requirements for CNG containers used for fuel storage in motor vehicles. FMVSS 304 includes tank testing provisions which are necessary to determine whether a fuel storage system meets the performance requirements. Manufacturers' labeling must indicate if a tank's useful service life is 10, 15, 20 or 25 years.[413] FMVSS 304 requires that "This container should be visually inspected after a motor vehicle accident or fire and at least every 36 months or 36,000 miles, whichever comes first, for damage and deterioration." NGV2[414] also requires in-service visual CNG tank inspection every 3 years or 36,000 miles, and its destruction and disposal after its service life. Based on limited experience to date with CNG buses and trucks, some SMEs estimated that the probability of such failure events due to aging, degraded CNG tanks used beyond their design life could be Medium, but the consequences potentially High.

When CNG tanks reach the end of their 15-25 years design life or service life, they should be decommissioned and replaced. There are reported explosions of expired or damaged CNG tanks

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411 See incident at http://seattletransitblog.com/2011/02/28/breaking-gas-explosion-at-pt-facility
412 See B. Hennessey, Jan 2012, SAE/GIM presentation at www.sae.org/events/gim/presentations/2012/hennesseynhtsa.pdf
413 See www.ngvi.com/tag/ngv2/
414 See www.transecoenergy.com/pages/CNG_Tank.htm

which remain in service, being unscrupulously resold through shops and online, e.g., on eBay; though these claims have not been substantiated by a Government agency.[415]

Robert Zalosh, a fire and explosions prevention expert from Firexplo, cited several tank explosion incidents involving degraded, damaged or expired CNG tanks.[416]

A national inventory of all CNG tanks on trucks and buses could aid in enforcing proper tank end of life disposal. In addition, required NGV training for all automotive mechanics who service NGVs could help to ensure that damaged CNG tanks are not placed back in service without the necessary inspection.

4.2.1.3 Prevention and Mitigation of CNG Tank Failure and Refueling Hazards

The regulatory requirement of FMVSS 304 (CNG Fuel Container Integrity) cited above is for CNG tank inspection every 36 months, after a fire or reportable DOT accident, or the removal of a tank from service after its expiration date. Compliance with FMVSS 301 (Fuel System Integrity) and FMVSS 303 (Compressed Natural Gas (CNG) System Integrity)[417]—which currently apply only to vehicles below 10,000 lbs GVW and to school buses regardless of weight—could further enhance the safety of CNG fueled MD/HDVs if their domain of applicability were extended to Class 3 and above vehicles.

The Clean Vehicle Education Foundation (CVEF) posts a long list of safety regulations, codes and standards applicable to CNG fueled vehicles, infrastructure and operations.[418] These include SAE, NFPA and ANSI pressurized vessel voluntary consensus standards and recommended practices. The Foundation reviewed the limited calendar service life for ANSI NGV2 and FMVSS 304 NGV fuel containers, and developed a CNG tank Safety Training and Inspection program for owners/operators.[419] The foundation also posted safe CNG tank refueling, decommissioning, venting, post-crash, and proper procedures and guidance to prevent high-risk venting scenarios[420] paying special attention to aftermarket conversions (see Figure 2-5).

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[415] American Trucking Association. 2009. Expanding ATA's Safety Agenda Executive Summary www.truckline.com/Newsroom/Policy%20Papers/Safety%20Task%20Force%20Report.pdf

[416] Zalosh, R. 2009. CNG and Hydrogen Vehicle Fuel Tank Failure Incidents, Testing, and Preventive Measures www.mvfri.org/Contracts/Final%20Reports/CNGandH2VehicleFuelTankPaper.pdf and postings at www.firexplo.com/

[417] See e-49CFR571 for FMVSS at www.ecfr.gov/cgi-bin/text-idx?c=ecfr&tpl=/ecfrbrowse/Title49/49cfr571_main_02.tpl

[418] NHTSA. 2010b. Tire Pressure Monitoring System Tests For Medium and Heavy Trucks and Buses www.nhtsa.gov/DOT/NHTSA/NVS/Vehicle%20Research%20&%20Test%20Center%20(VRTC)/ca/capubs/811314.pdf

[419] See www.cleanvehicle.org/technology/cylinder.shtml

[420] Clean Vehicle Education Foundation. 2010. How Safe are Natural Gas Vehicles? www.cleanvehicle.org/committee/technical/PDFs/Web-TC-TechBul2-Safety.pdf, Clean Vehicle Education Foundation. 2012. Fatal accident removing cylinder solenoid valve www.cleanvehicle.org/technology/ValveFatality.pdf

CVEF industry best practices to prevent and/or mitigate hazards related to vehicle tank or refueling infrastructure CNG leakage leading to potential fires and explosions include: adequate training of maintenance staff and operators, frequent inspections, emergency response planning and preparedness, and engineered controls. The literature recommends voluntary compliance with industry best practices, standards and guidelines for CNG tank failure and refueling hazard minimization, and avoidance measures. These include how to:

- Provide methane gas and fire detectors both on-board the vehicle, and in depots and at fueling station.
- Ensure that pressure relief devices (PRDs) are mounted on the CNG high-pressure tank and piping subsystem.
- Provide a manual CNG shut-off valve for back up and to safeguard and isolate the fuel storage system from the engine.
- Install fire extinguishers to respond to leaks and prevent or extinguish fires.
- Safe vent CNG tanks for maintenance or replacement (using automated or manual venting) after a crash, and/or any piping and tubing that leaked.
- Ensure compliance with SAE best practices for CNG MDHD trucks, including SAE J2406 (Recommended Practices for CNG Powered Medium and Heavy-Duty Trucks), SAE J2343 (recommended practices for LNG-powered heavy-duty trucks).
- Comply with fire safety NFPA 52[421] and NFPA 57[422] codes applicable to any vehicle and/or facility that refuels CNG or LNG vehicles.
- Install engineering controls including: methane detectors, visual/audible alarms, and other safeguards to prevent ignition and vehicle fires in NGV refueling depots. These are recommended over reliance on process controls, such as manually opening doors or vents whenever an NGV is brought into a shared indoor facility.

4.2.2 Safety of LNG-Fueled MD/HDVs and Refueling Systems

Cryogenic Liquefied Natural Gas (LNG) use as a transportation fuel is accelerating. As discussed in Chapter 2, LNG is better suited to over the road short haul HD operations than CNG (1 gal of diesel has the same energy contents as 1.67 gals LNG, but 135 scf CNG). There are few refueling stations at present; these mostly are operated for corporate or city fleets. Currently there are only 6,000 LNG fueled vehicles in the United States, mostly transit buses in Dallas and Austin, TX; El Paso and Phoenix, AZ; and Los Angeles and Orange County, CA. Between 2010, the ports of Los Angeles and Long Beach will replace 800 drayage trucks with LNG trucks, with 219 deployed by December 2012.[423] Waste Management, Inc. has operated an LNG fueled refuse truck fleet for years in CA and PA, and just added its 1000th LNG truck to the fleet

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[421] National Fire Protection Association. 2010. NFPA 52: Vehicular Gaseous Fuel Systems Code www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=52

[422] National Fire Protection Association. 2002. NFPA 57: Liquefied Natural Gas (LNG) Vehicular Fuel Systems Code www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=57

[423] See CARB, May 12, 2012, "Heavy Duty Natural Gas Truck Replacement Program" at www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/technology_integration/arravt045_ti_white_2012_o.pdf

(Figure 5-3).[424] NREL has conducted several evaluations of the Waste Management, Inc. LNG truck fleet, showing emerging design and operational improvements over time.

There are a few commercial producers of LNG and some distribution firms (mostly via LNG tanker trucks) that supply LNG fueling stations. LNG Dedicated tanker truck operators include: Tri-Mac, Transgas, Southeast LNG, J.B. Kelley, and L.P. Transportation.

The National Petroleum Council (NPC) Future Transportation Fuels (FTF) recent studies included a qualitative safety evaluation of LNG as an emerging transportation fuel, with associated risks relative to petroleum discussed in the literature and Chapter 2.[425]

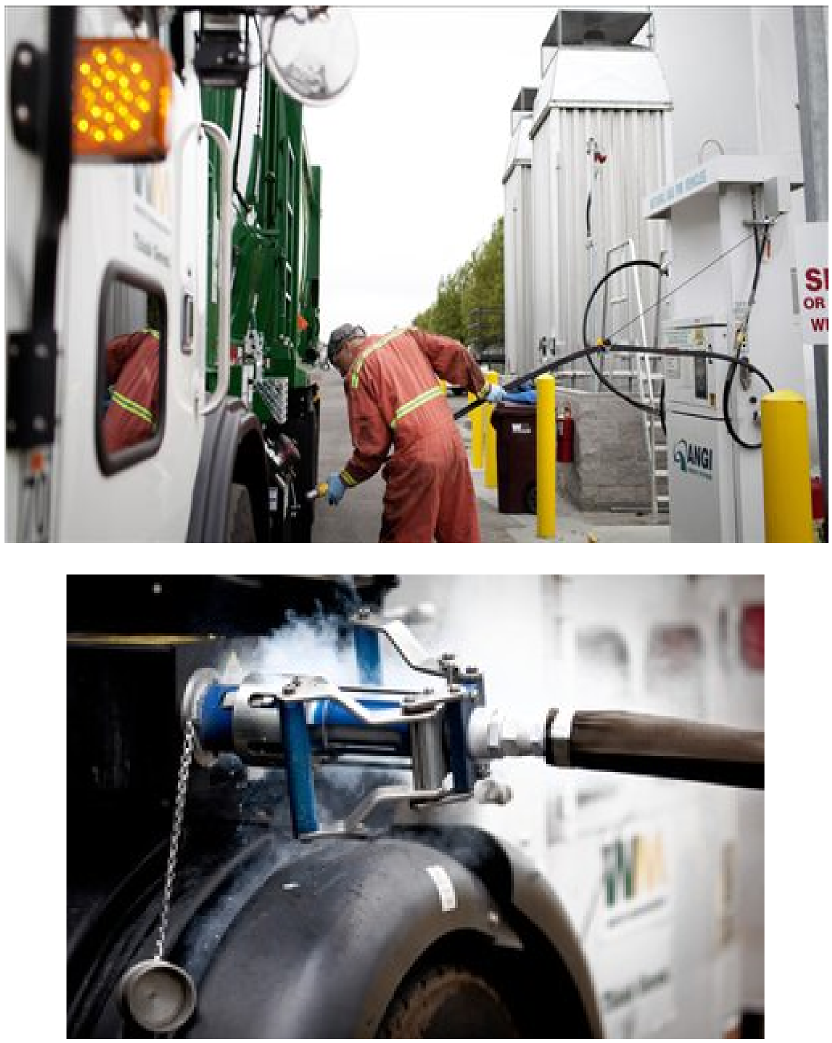

Figure 4-3: Refueling a Waste Management LNG Truck[426]

[424] See 2001 NREL report at Waste Management's LNG Truck Fleet Alternative Fuels Data at www.afdc.energy.gov/pdfs/waste_lng_final.pdf and www.wm.com/about/press-room/2011/20110712-wm-adds-1000th-natural-gas-truck.jsp

[425] National Petroleum Council. 2012. An Initial Qualitative Discussion on Safety Considerations for LNG Use in Transportation www.npc.org/FTF_Topic_papers/19LNG_Transportation.pdf

This NPC white paper on LNG safety cited the excellent safety record for LNG transportation. There were only 20-30 over-the-road incidents since 1971 that involved road crashes; less than half of which led to spills, and only one resulted in a fire with driver injury. In one crash, the LNG vessel on a crashed tanker truck maintained integrity when diesel tanks of the other vehicle caught fire. Potential safety hazards include cryogenic liquid burns from drivers contacting spilled LNG and the potential for fire or explosion. However, engineered system safeguards, such as double walled steel container tanks with insulation, PRDs, and inspections to prevent steel tank embrittlement and cracking, reduce the risk of a boiling liquid expanding vapor explosion (considered a worst-case scenario in the event of a fire or crash). Multiple safeguards are used for refueling equipment and procedures. Fire suppression equipment and training for maintenance personnel and emergency responders could mitigate the consequences of such an LNG truck mishap.

4.2.3 Flammability of Lightweighting Materials and Toxicity of Burning Byproducts

As discussed in Chapter 3.2.9, some SMEs raised potential safety concerns regarding the fire safety and flammability of some materials used for automotive light-weighting. Although there is little to no actual experience to date, the SMEs conjecture was that the probability of such occurrences, assuming larger scale deployment of lighter MD/HDVs, could be low to medium, but a fire related consequences could be medium to high**.**

Various carbon-fiber reinforced polymers (CFRP), resins, and plastics are typically more flammable than steel, and lighter weight metals (high performance steels, aluminum and titanium). Use of CFRP and glass fiber composites in phenolic, with high stiffness to weight ratios, are some of the emerging structural materials used for vehicle mass reduction. Other material systems include honeycomb sandwich structures, high performance steels, and titanium and magnesium alloys to achieve “mass compounding” benefits that reduce overall MD/HD verse weight in order to enhance fuel efficiency.

NHTSA held several workshops to examine the relationship between vehicle mass and size and crash safety in 2013[427] and 2011. Although lightweighted vehicles may offer improved maneuverability and shorter stopping distance, they could also result in reduced crash survivability in certain crash scenarios and/or in vehicle fires. While there is no supporting data in the literature regarding the crashworthiness of light-weighted Class 2b to 8 vehicles, there are some general safety concerns about the materials. Knowledge of fire and shatter hazards associated with the composites used in aircraft and marine applications can be transferrable to MD/HDV composite applications.

The fire safety and health hazards of byproducts from burning composites include the potential release of volatile organic compounds, toxic microscopic fibers, and combustion products were a

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[426] Wall Street Journal, May 23, 2012, “Will truckers ditch diesel?” at http://online.wsj.com/article/SB10001424052702304707604577422192910235090.html#printMode

[427] See mass-size-safety May 2013 workshop presentations at www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/NHTSA+Vehicle+Mass-Size-Safety+Workshop; and the 2011 workshop transcript at www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/NHTSA+Workshop+on+Vehicle+Mass-Size-Safety

secondary concern. Toxic fire byproducts, dispersal, and inhalation of fine fibers pose health hazards to emergency responders and bystanders.[428] Carbon fiber and epoxy materials ignite easily and burn rapidly. Smoldering or burning composites produce toxic smoke containing irritants, combustion gases (HCl, HBr, NO2), soot particles and sharp fibers, which in turn can cause choking, cough and disorientation, as well as long-term health problems following exposure.[429]

Passive fire protection coatings such as Vermitex and fire suppression equipment in the cab could prevent and mitigate flammability hazard and toxicity of by-products for new MD/HDV materials. However, fire safety and environmental health issues for specific lightweighting tractor cab and trailer bed materials would benefit from further study. Also, fire prevention and suppression best practices from light-weighted composite-rich aircraft skins and seating may be useful, if proven to be cost-effective.[430]

Brittle failure, or shattering of composite body panels in a crash- even without any fire- may also pose hazards from the release of fine particulates that irritate skin and lungs, and could require EMTs to wear respirators for protection. Materials Safety Data Sheets (MSDS) for specific fuel efficient lighter weight truck and trailer materials could help in the evaluation of the potential severity of a crash with or without resulting fire.

A 2007 Volpe Center study for NHTSA that developed a safety roadmap for future PCIVs[431] that included both structural and fire safety is also relevant to MD/HDV lightweighting materials options. Plastic foam filler used in interior seating and door padding could also release toxic volatile organic compounds and carbon monoxide in a crash-fire.

4.2.4 Safety Performance of Single Wide Base Tires and Low-Rolling Resistance Tires

Wide base single tires, also called "super-singles," and LRRs are being increasingly adopted by MD/HDV fleets, as discussed in Chapter 2.7.2. In Chapter 3.2.7 we reported that some SMEs perceived an increase in stopping distance or reductions in stability and control on slick highways when using LRR and/or wide base tires. In their opinion, this hazard probability could be medium but the consequence potentially medium to high.

As indicated in Chapter 2.7.2, this research identified no studies that document reduced safety performance for either LRR or wide-base tires. Indeed, EPA's testing of conventional and LRR

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428 Gandhi, S. 1999. Postcrash Health Hazards from Burning Aircraft Composites www.aviationfirejournal.com/aviation/library/VOL6-Hazards.pdf

429 Flight Safety Foundation. 2008. Downwind Debris http://flightsafety.org/asw/sept08/asw_sept08_p40-43.pdf?dl=1

430 Gandhi, S., & Lyon, R. E. 1998. Health Hazards of Combustion Products From Aircraft Composite Materials www.tc.faa.gov/its/worldpac/techrpt/ar98-34.pdf

431 Brecher, A. 2007. A Safety Roadmap for Future Plastics and Composites Intensive Vehicles www.nhtsa.gov/DOT/NHTSA/NVS/Crashworthiness/Vehicle%20Aggressivity%20and%20Fleet%20Compatibility%20Research/810863.pdf

Class 8 tractor and trailer tires found no significant correlation between the snow traction rating and the coefficient of rolling resistance.[432]

Since a LRR wide base tire replaces twin tires, a high-speed blowout on the road of a wide base tire, especially for heavy loads, could potentially affect the vehicle balance and stability at higher speeds. However, literature from the EPA's SmartWay Program indicates that wide base tires can improve the stability and control of combination trucks and tank trailers by allowing the tank to be mounted lower.[433] A NHTSA study of decreased tire pressure impacts on safety indicated that tire pressure monitoring is an important safety factor.[434] Although the NHTSA crash files did not contain direct evidence that points to low tire pressure as the cause of any particular crash, low tire pressure was considered a possible factor in crashes due to loss in traction and blowout failures of underinflated tires, as well as increased stopping distance.

The use of TPMS for wide base tires (or with any MD/HDV tires) may prevent under-inflation and reduce the risk of crashes due to flat tires and blowouts.

4.2.5 Longer Combination Trucks . .

Several types of LCV configurations with extra length and gross vehicle weight (GVWR) ranging from 80,000 to over 120,000 lbs., have been allowed to operate (with special driver training requirements and varying restrictions) in 23 States to date (Figure 4-4). Operation is permitted on some interstate, rural two-lane, or city roads and interchanges. Advocates for Highway and Auto Safety strongly opposed lifting the 1991 restrictions on LCV highway operations, citing NHTSA, IIHS, and UMTRI data.[435]

The American Trucking Association (ATA) supports seven limited reforms to current truck size and weight regulations that would allow LCVs in order to increase the productivity, fuel efficiency, reduce truck traffic and environmental emissions.[436] The Owners Operator Independent Drivers Association opposes LCVs[437] due to several safety concerns that may contribute to LCV crash hazards in mixed vehicle traffic, especially on urban freeways and interchanges:

- Off-tracking at both low and high speeds, when tractor trailers turn in a curve or at intersections and encroach into shoulders and adjacent lanes, endangering both parallel and/or oncoming traffic. At low speeds, rear wheels track inside the path of the front

[432] See "Snow Traction Performance of Low Rolling Resistance Drive Tires for Class-8 Tractor Trailers," SAE Paper 2012-01-1918 at http://papers.sae.org/2012-01-1918/

[433] See www.epa.gov/smartway/documents/partnership/trucks/partnership/techsheets-truck/EPA-420-F10-041.pdf

[434] See Tire Pressure Monitoring Final Rule (Part III-Safety problem) at www.nhtsa.gov/cars/rules/rulings/tirepresfinal/safetypr.html

[435] See 2005 Factsheet "The Dangers of Large Trucks" at www.saferoads.org/issues/fs-trucks.htm

[436] See "ATA Summary of Truck Size and Weight Studies" at www.transportationproductivity.org/Studies/ATA_Summary_of_TruckSizeandWeightStudies.pdf and www.truckline.com/AdvIssues/HighwayInf_Fund/Documents/Proposed%20Reforms%20to%20Federal%20Truck%20Size%20and%20Weight%20Limits.pdf

[437] See LCV issues at www.ooida.com/OOIDA Foundation/issues/LCVs.shtml

wheels while at high speeds they track outside the path, with widths varying with consist length and weight.

- Larger and heavier loaded LCV big rigs cause more and costly damage to infrastructure (pavements, bridges, and shoulders) that is not designed to sustain such loading, even though operators distribute the load over more axles.
- Trailer sideways sway and jack-knifing motion on open road (even when not windy), which is amplified rearward for longer LCVs like triples and causes encroachments into adjacent lanes and traffic, especially in response to sudden steering.
- Lower stability of LCVs, which are more prone to rollover due to connections between the second and third trailer.
- Longer braking and stopping distance that can cause crashes in sudden braking, and require special and more frequent inspections and brake adjustments.
- Difficulties LCVs have when accelerating and merging with traffic at interchanges, due to the mismatch in speed and acceleration abilities of LCVs relative to other vehicles.
- Difficulty of LCVs in maintaining speed on inclined roads, both climbing and for down-grade, compared with other vehicles.
- Hazards of splash and spray from LCVs to vehicles when passing long LCVs in rainy, fog, windy, or snowy conditions (due to blinding spray on windshields, and side-winds).
- Difficulty of LCVs parking in rest areas and at weigh in motion (WIM) stations.

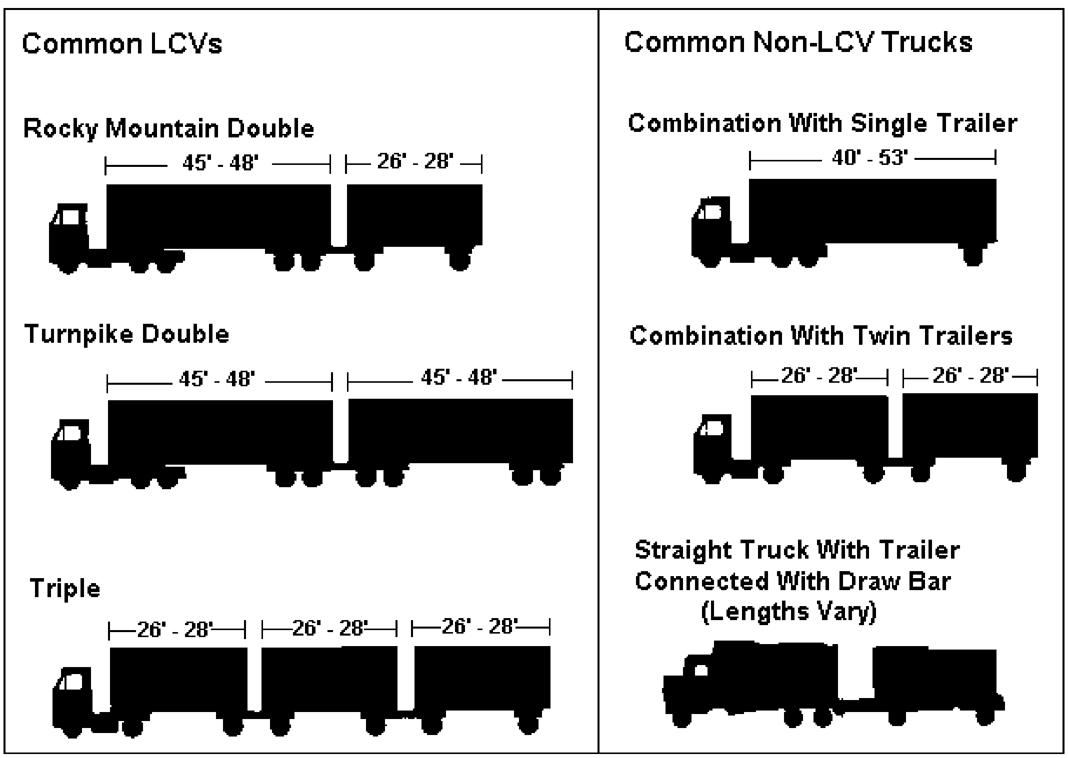

Figure 4-4: Three Types of LCV Configurations[438]

[438] Source: www.usroads.com/journals/rej/9708/re970806.htm

The SMEs interviewed in Chapter 3 believed that potential LCV hazards have a low probability; but consequence severity could be medium to high. However, several studies on the relative safety of LCV operations that compared to other trucks that were conducted over the past 20 years indicate that such hazard assessment remains inconclusive because of insufficient data, and the small number of LCVs, as well as no causal linkage details in the crash data collected.[439] The American Automobile Association (AAA) has conducted pilot studies in five States that allow LCV operations and determined that analysis is not possible due to inadequate detail in crash data collection, and lack of reliable data. California DOT (Caltrans) conducted LCV field tests in 1983 on a variety of roads and diverse speeds and determined that problems outweigh the benefits.[440]

The FHWA has conducted several Truck Size and Weight studies, including a 2000 scenario description of LCV nationwide traffic[441] for the North American Free Trade Agreement (NAFTA), and a safety evaluation that required aggregating 6 years of crash data (1995-99) to get meaningful statistics for a safety comparison. These FHWA studies concluded that data were not adequate to make reliable risk predictions, and that fewer LCVs on the roads would reduce the overall travel risk exposure more than reducing truck crashes.[442]

The most comprehensive 2009 safety analysis of LCVs[443] reviewed multiple Over-Size/Over-weight (OS/OW) large truck crash data sets (TIFA/UMTRI, FARS, weigh station data-WIM, LTCCS, TRB) and concluded that as commercial vehicles become larger and heavier, crash rates decrease, but crash severity increases. However, due to lack of consistency and quality in crash data collections, findings on LCV relative safety are inconclusive.

The most recent cost-benefit reassessment of LCVs conducted by the University of Wisconsin National Center for Freight and Infrastructure Research and Education (CFIRE) in 2012 reviewed the literature for LCV pros and cons. It found as many claims for safer LCV operations, as for less safe impacts, and concluded that the benefits outweigh costs and warrant expanding nationwide LCV operations.[444]

In a potentially worst case, high consequence scenario, multiple vehicle crashes might occur on a two-lane highway when small vehicles are trying to overtake a long, slow-moving triple-trailer LCV-especially in low visibility hazardous weather- and crash with oncoming traffic, causing multiple fatalities, injuries and vehicle damage. No such worst case, pile-up crash scenario was

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[439] See AAA Foundation for Traffic Safety, "Longer Combination Vehicle Safety Data Collection," 2000, at https://www.aaafoundation.org/sites/default/files/lcv.pdf

[440] See CALTRANS Longer Combination Vehicles posting at www.dot.ca.gov/hq/traffops/trucks/exemptions/lcv.htm

[441] See Chapter III, Scenario Descriptions at www.fhwa.dot.gov/reports/tswstudy/Vol3-Chapter2.pdf

[442] *See at Western Uniformity Scenario Analysis - Chapter 7 Safety:* www.fhwa.dot.gov/policy/otps/truck/wusr/chap07.htm

[443] "A Synthesis of Safety Implications of Oversize/Overweight Commercial Vehicles" by D. S Turner et al., University Transportation Center of Alabama (UTCA) report 07115, June 2009 at http://utca.eng.ua.edu/files/2011/10/07115-Final-Report.pdf

[444] Adams, T., Kleinmaier, D., Marach, A., Helfrich, G., Levine, J., & Bittner, J. 2012. Longer Combination Vehicles: An Estimation of their Benefits and Public Perception of Their Use www.wistrans.org/cfire/.../CFIRE_05-01_Final_Report.pdf

found in a 2003 NHTSA/NCSA study of LCV crash types[445] (see Table 15a, based on 1996-99 crash data).

Countermeasures for potential LCV hazards, including both prevention and mitigation, could include improved driver training and certification, restricted road operation, mandated safety appliances (antilock brakes (ABS), electronic stability control (ESC)) and automated trailer steering (ATS), which enables steerable multiple axles for improved LCV stability and control, potentially eliminating or reducing sway related hazards.[446]

4.2.6 Aerodynamic Components

Aerodynamic components include a range of devices mounted onto a vehicle body, including those certified by the EPA SmartWay program[447] as FE technologies:

- trailer gap reducer and trailer side skirts (used in combination with one another);
- trailer boat tail and trailer side skirts (used in combination with one another);
- advanced trailer end fairing; and
- advanced trailer skirts.

For combination trucks, these components include cab extenders, trailer skirts, boat tails, and streamlined mirrors and bumpers. As discussed in Chapter 2, up to two-thirds of long-haul tractors and one-sixth of trailers in the United States are equipped with some aerodynamic FE technologies.

Some SMEs interviewed were concerned with potential incidents of aerodynamic components detaching while the vehicle traveled on a busy highway or urban roadway. Although trucks are more likely to strike stationary objects that damage a fairing while off-highway, e.g., at a loading or transfer facility, the maximum severity of a detachment incident would be on-highway at high speed. In a worst case high-consequence scenario, a multiple vehicle crash could occur if a small vehicle trailing a combination truck on a highway was struck by detached aerodynamic fairings. In such a scenario, the detached fairing could penetrate the windshield of a trailing vehicle, leading to fatalities, injuries, and vehicle damage.

To date there are no known examples of such incidents reported in the literature. Thus, up to now the probability of occurrence for such detachment incidents appears to be very low. There is no a priori reason to expect that large scale adoption of aero devices on Class 8 tractor-trailers will lead to a higher probability of occurrence for highway fairing detachment incidents and potentially resulting crashes, though – in principle – the probability of individual aero detachment failures could scale to the number of devices deployed.

Since aerodynamic fairings are designed to minimize weight, with typical trailer skirts weighing approximately 200-pounds, they are unlikely to cause severe primary damage to other enclosed

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[445] See Report No. DOT HS 809 569 June 2003, An Analysis of Fatal Large Truck Crashes at www-nrd.nhtsa.dot.gov/Pubs/809-569.pdf
[446] See Drastic productivity gain for Large Truck Operations with Automated Trailer Steering, 2009 at www.engr.sjsu.edu/media/pdf/res/coe_res_facdev_grant_symp_040309_tsao_ppt.pdf
[447] See www.epa.gov/smartway/technology/aerodynamics.htm

(i.e., non-motorcycle) vehicles on the highway in a detachment scenario. However, under special circumstances the resulting debris could result in vehicle crash hazards from avoidance maneuvers by nearby drivers.

While early designs of underbody fairings tended to be monolithic and were prone to snapping in a bottoming-out collision with a curb or railway crossing, newer designs employ composite materials (Figure 4-5) and are capable of flexing up to 90 degrees.[448] Videos of various skirts depict the vehicle being driven over 2-3 foot tall snow banks and curbs without breaking or detaching the skirt.[449] In a rear-end collision with a boat-tail equipped vehicle, the lower panel of the boat tail may be vertically aligned with the windshield of cab-over trucks, buses, or passenger vans.[450] Depending on the boat tail panel construction, a worst case crash scenario could involve penetration of the windshield and possibly fatal injuries to the trailing vehicle's occupants. However, no reported incidents of this type could be documented by our literature and Internet search.

Figure 4-5: Trailer Skirt Made From Resilient Composite Material[451]

International research sources reviewed and experience abroad [452,453,454,455,456,457] suggests that covering the cavity between the front and rear wheels of MD/HDVs can provide a safety benefit

[448] Freight Wing Incorporated. 2011. Aeroflex www.freightwing.com/aeroflex.php
[449] Golsch, K. 2012. HD Vehicle Fuel Economy Improvements through Aerodynamic and Front End Airflow Technological Advances
[450] Patten, J., Poole, G., Mayda, W., & Wall, A. 2010. Trailer Boat Tail Aerodynamic and Collision Study www.tc.gc.ca/eng/roadsafety/safevehicles-motorcarriers-environment-boat-tails-1307.htm
[451] Freight Wing Incorporated. 2011. Aeroflex www.freightwing.com/aeroflex.php
[452] SWOV – Dutch Road Safety Research Institute. 1996. Closed Sideguards on Trucks: Less Fuel Consumption for Trucks, Safer Feeling for Vulnerable Road Users
[453] Cookson, R., & Knight, I. 2010. Sideguards on heavy goods vehicles
[454] Globe and Mail, Scrapped Canadian study found early promise for safer truck design, www.theglobeandmail.com/news/national/scrapped-canadian-study-found-early-promise-for-safer-truck-design/article10600215/

in side-impact collisions with non-motorists, such as bicyclists and pedestrians, by reducing the likelihood of side underrun by the rear wheels. For example, the fraction of fatal side-impact collisions between bicyclists and trucks decreased 61 percent in the U.K. following a national implementation of cavity-covering sideguards on heavy trucks.[458] While sideguard implementation on U.S. trucks is nearly nonexistent,[459] decades of both aerodynamic and non-aerodynamic sideguard implementation on trucks in the UK,[460] EU,[461] Japan, and Brazil raise the question of whether North American truck skirts designed for aerodynamics and fuel economy could also potentially reduce the severity of under-ride crashes with non-motorists. At least one North American aerodynamic truck skirt manufacturer, Laydon Composites, already claims that its sideskirt meets the European lateral under-ride protection standard.[462] A 2013 National Research Council Canada study funded by the Transport Canada EcoTechnology program[463] examined the level of side underride protection potentially provided by three commercially available aerodynamic trailer skirt models.[464] The preliminary 2010 NRC Canada report[465] concluded: "The effectiveness of the sideguards on heavy vehicles has been demonstrated by a UK study."

Another potential safety hazard scenario identified by SMEs as result of aerodynamic fairings adoption is the potential for making vehicle underbody inspection more difficult. The highest consequence scenario would be a failure to detect safety-critical vehicle issues, such as deficient brakes, leading to subsequent on-road failure. If brakes were to fail, a severe crash could result. However, the likelihood of this scenario was considered by SMEs to be low. No cases of inspection oversights that have caused subsequent crashes are known to be explicitly linked to aerodynamic components. (Of course, if an inspection fails to identify an existing issue that causes a later crash, this data may simply not exist.) However, interviews with truck mechanics and maintenance staff at a major fleet suggest that aero components do not hinder necessary

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455 Riley, B. S., Penoyre, S., & Bates, H. J. 1985. Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards http://trid.trb.org/view.aspx?id=237955

456 Lambert, J., & Rchnitzer, G. 2002. Review of Truck Safety: Stage 1: Frontal Side, and Rear Underrun Protection

457 I Knight et al. 2005. Integrated Safety Guards and Spray Suppression--Final Summary Report at www.roadsafetyobservatory.com/Evidence/Details/11356

458 Ibid. as 446

459 Limited municipal pilot deployments totaling approximately 40 vehicles have taken place in Portland, OR and Boston, MA since 2010, in addition to an unfunded sideguard mandate in Washington, D.C. These pilot programs are too recent and small-scale to have produced statistically significant national crash data.

460 Riley, B. S., Penoyre, S., & Bates, H. J. 1985. Protecting Car Occupants, Pedestrians, and Cyclists in Accidents Involving Heavy Goods Vehicles by Using Front Underrun Bumpers and Sideguards http://trid.trb.org/view.aspx?id=237955

461 European Union. 1989. European Council Directive 89/297/EEC http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31989L0297:EN:HTML

462 National Research Council. 2010a. Technologies and Approaches to Reducing the Fuel Consumption of MD/HD Vehicles www.nap.edu/openbook.php?record_id=12845&page=R1

463 www.tc.gc.ca/eng/programs/environment-etv-menu-eng-118.htm

464 Globe and Mail, Scrapped Canadian study found early promise for safer truck design, www.theglobeandmail.com/news/national/scrapped-canadian-study-found-early-promise-for-safer-truck-design/article10600215/

465 Patten, J.D. and Tabra, C.V. Side Guards for Trucks and Trailers Phase 1: Background Investigation, 2010. www.worldcat.org/title/side-guards-for-trucks-and-trailers-phase-1-background-investigation/oclc/797259567

access.[466] In most European and Asian countries that adopted aerodynamic fairings as standard equipment on MD/HDVs normally present during inspections, access was not impeded. Clean carrier truck fleets, which are early adopters of aerodynamic packages, all demonstrated superior safety performance based on FARS and MCMIS databases versus conventional carriers (see Chapter 4). Moreover, the overall crash rate of trucks has not increased over the past decade, even as the deployment of aerodynamic devices has greatly increased.

To further reduce the likelihood of this scenario, potential countermeasures for inspection interference could include the use of mirrors by vehicle inspectors for inspecting certain items instead of crawling under the vehicle, making fairings removable, providing access hatches, or using hinged designs that provide on-demand access for inspectors. For visual inspection, certain fairings or wheel covers could also be made transparent.

4.2.7 Potential Fires from Overheated EV/PHEV Battery

Longer-term experience with the use of high performance lithium ion batteries (LIB) in rechargeable energy storage systems (RESS) has accumulated from several thousands of advanced hybrid electric and electric transit buses and shuttles. By 2013, over 11 percent of transit bus fleets were hybrid and electric and more on order, according to APTA. Large transit agencies with safety operational experience include the New York MTA operating over 1600 hybrid buses, and the Washington Metrobus and King County DOT with hybrid fleets of over 600 buses each. This operational fleet experience offers safety "lessons learned" relevant to emerging commercial HEV/EV/PHEV counterparts. LIBs may pose potential risks due to thermal runaway when overheated or explosion and fire when the cell is ruptured. Flammable lithium and vented hydrogen or oxygen may initiate and sustain fires, and corrosive or toxic electrolyte could leak if the battery is breached. Although there are very few documented fire incidents in hybrid-electric buses to date and some SMEs considered that although this hazard probability was low, they believed the consequence severity could be medium to high. Therefore, we documented reported incidents below to provide the context for such a scenario.

U.S. hybrid and electric transit buses models deployed and featuring LIBs integrated in high power and capacity RESS include: the Daimler Bus NA Orion VII, the DesignLine EcoSaver IV, the El Dorado National Axess, Gillig HEB models with Allison dual-mode compound split propulsion, North America Bus Industries (NABI) diesel electric with ISE/Bluways ThunderPower, the Proterra composite electric or fuel cell buses with TerraVolt and Altair Lithium Ion Titanate (LTO) LIBs, and the New Flyer Xcelsior.

The Orion VII diesel-electric hybrid buses with A123 Lithium Iron Phosphate (LiFePO4) batteries[467] have been in service since 2007, and have been documented as being both energy-efficient and environmentally friendly.[468] These batteries have greater energy density and power and are 3,000 pounds lighter than the previously used lead acid Orion battery packs, thus

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[466] Navistar. 2012. Aerodynamic and Tire Technology Adopter Interviews

[467] See www.a123systems.com/solutions-transportation.htm

[468] See TRB/TCRP Report 132, "Assessment of Hybrid Electric Transit Bus Technology," December 2009, www.trb.org/Main/Blurbs/Assessment_of_HybridElectric_Transit_Bus_Technolog_162703.aspx and "BAE/Orion Hybrid Electric Buses at New York City Transit: A Generational Comparison (NREL/TP-540-42217)."

improving bus fuel economy. They also have a stated six-year design life with lower operating and lifecycle costs. The BAE's "next generation HybriDrive" may enable more flexible modular RESS configurations with electronically-controlled cooling and APU (fuel cells or other options) to be placed on the roof for easy access and maintenance, for fuel cell hybrid-electric buses.

BAE's HybriDrive[469] is also compatible with other hybrid and electric bus platforms and RESS options: the New Flyer Industries Xcelsior (XDE40) 40-foot diesel HEB also uses the BAE HybriDrive with LiFePO4 batteries (from Lithium Technology Corporation). The LIB delivers 200 kW peak power and is cooled with forced air. The Washington Metro Area Transit Authority (WMATA) received 152 such Xcelsior buses in 2011 and ordered 95 more in 2012 for 2013.[470]

Information on LIB failures and maintenance issues can also be found in NREL evaluations of hybrid and electric transit bus fleets upgraded with different LIB chemistries, which are operating in many U.S. cities.[471, 472] These reports evaluate hybrid and electric bus fleets such as the New York City MTA's BAE Orion diesel-hybrid bus fleet, Long Beach Transit's gasoline-electric hybrids, King County Metro's Allison hybrid-electric buses, and Knoxville Area Transit's Ebus electric buses and trolleys. For instance, the NREL multi-generational comparison of Orion/BAE hybrid-electric buses operating in the New York City MTA's transit fleet[473] identified the key LIB performance, durability, and safety improvements needed for transit reliability, availability and durability.[474]

On October 28, 2011, NHTSA's Office of Defect Investigation issued a safety recall and corrective modifications or replacement of LIBs in Daimler Orion VII hybrid-electric buses. After several incident investigations due to accumulation of debris and moisture that potentially breached electrical isolation,[475] 1,300 Orion VII hybrid buses with the BAE HybriDrive and RESS using A123 LiFePO4 batteries (manufactured in November 2008), and some earlier 2006–07 models retrofitted with LIBs were recalled to replace the battery modules on the bus roof.

The BAE Systems HybriDrive[476] integrated a LiFePO4 battery chemistry based on its superior thermal stability, energy capacity, and operational safety, as well its modular, compact, lightweight design, and longer cycle life (over 6 years). Even though the roof placement did not require active battery cooling it allowed the debris and moisture accumulation to cause potential short-outs and fires.

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469 See www.hybridrive.com/

470 See news at www.newflyer.com/index/2012_08_07_wmata_additional_order

471 See transit hybrid fleet reports posted at www.afdc.energy.gov/afdc/fleets/transit_experiences.html?print

472 See postings listed at www.afdc.energy.gov/afdc/fleets/transit_experiences.html

473 See "As Hybrid Buses Get Cheaper, Cities Fill Their Fleet," *New York Times*, October 22, 2009, www.nytimes.com/2009/10/22/automobiles/autospecial2/22BUS.html?_r=1

474 See Clean Air Initiative: Infopool–Hybrid Bus postings at www.cleanairnet.org/infopool/1411/propertyvalue-17735.html#h2_5

475 See Orion 7 Hybrid Bus Recall at http://recallcast.com/recalls/2011/oct/28/daimler-buses-north-america-inc-electr-11v523000/ and at www.safercar.gov and http://recallcast.com/recalls/tag/orion/

476 See www.hybridrive.com/hybrid-transit-bus.asp and www.hybridrive.com/lithium-ion-energy-storage-system.asp

This recall affected more than 1,600 Orion buses operating in New York City. The 2011 Orion VII safety recall has already affected many urban transit fleets in the United States and contributed to Daimler's discontinuing the manufacture and marketing of Orion VII hybrid buses in the United States and Canada in April 2012.[477]

The New Flyer manufacturer of Xcelsior buses, which also use the BAE HybriDrive RESS with A123 LIBs, notified NHTSA in March 2012 that it was recalling them to correct a similar RESS that could cause a LIB short and pose fire hazards. A total of 47 hybrid Xcelsior Metrobuses in the Washington, DC, area were also pulled from operation for inspections and corrective retrofits of LIBs by BAE Systems.[478]

To date, both the incidence and severity of hybrid and electric bus safety incidents involving LIBs overheating, degassing, or having electrical short-out incidents are very low. Only 10 similar incidents have occurred in the United States and Canada in the past decade out of more than 2,200 operating hybrid buses, with no resulting fatalities or injuries.

Although hybrid and electric delivery trucks and vans in cities have similar duty cycles, centralized maintenance, and scheduled recharging to transit buses, long-haul trucks experience more demanding battery charge/discharge duty cycles. Potential hazards for this application could include the battery overheating or failing suddenly in severe weather condition, potentially causing fires or crashes.

4.2.7.1 Electrical Hazards Prevention and Mitigation

After a Chevy Volt fire and defect investigation,[479] NHTSA held a technical workshop on electric vehicle safety [480] (May 2012). In cooperation with the National Fire Protection Association (NFPA), issued an "Interim Guidance for Electric and Hybrid Vehicles Equipped with High Voltage Batteries"[481], to assist owners/operators, first responders, and towing/recovery operators. The Guidance is applicable to all hybrid and electric vehicles, including MD/HDVs.

At the May, 2012 Electric Vehicle Safety (EVS) workshop several presenters discussed the potential hazards specific to heavy-duty hybrids.[482] For instance, the high voltage cables and

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477 See www.newschannel6now.com/story/17736988/daimler-buses-reconfigures-operations-in-north-america?clienttype=printable

478 See news item at washingtonexaminer.com/article/416416

479 PE11037; www-odi.nhtsa.dot.gov/owners/SearchResults?searchType=ID&targetCategory=I&searchCriteria.nhtsa_ids=PE11037

480 See postings for May '12 workshop and Jan '12 Interim Guidance Report No. DOT HS 811 574 at www.nhtsa.gov/Vehicle+Safety/Electric+Vehicle+Safety+Symposium

481 See NHTSA "Interim Guidance for Electric and Hybrid Vehicles Equipped with High Voltage Batteries" and o postings at www.nhtsa.gov/About+NHTSA/Press+Releases/NHTSA+Statement+on+Conclusion+of+Chevy+Volt+Investigation

482 See NHTSA EVS workshop summary and presentations posted at www.nhtsa.gov/About+NHTSA/Press+Releases/NHTSA+Hosts+Technical+Workshop+on+Electric+Vehicle+Safety

post-crash stranded energy in the high power hybrid and/or electric MD/HDV LIBs may pose hazards of electrocution and shock to maintenance technicians and/or emergency responders after a crash or fire incident. The probability of high voltage battery-related electrical shorts, electrocution and fire hazards can be reduced through compliance with FMVSS 305 (which currently applies only to vehicles lighter that 10,000 lbs GVW, and deals with electrolyte leakage and loss of electric isolation due to specific crash scenarios mandated by FMVSS 301), and adherence to the NHTSA interim Safety Guidance.[483]

NHTSA is continuing to conduct research on failure scenarios and safety of RESS and LIBs. Such potential hazards may be preventable or mitigated through redundant engineering design, packaging, and abuse testing of batteries and the RESS subsystem. Effective prevention includes the use of a LIB battery management system (BMS) and thermal management system (TMS), which monitor the voltage and temperature of power electronics, and which are programmed to detect faults and shutdown. In addition, crashworthy packaging prevents penetration and leakage of electrolyte from the battery in a crash.

OEMs are observing the voluntary SAE electrical safety and battery testing standards (e.g., J2929 and Battery Abuse Testing Handbook)[484] as generally recommended best safety practice for emerging MD/HDV designers, manufacturers, owners and operators. There are numerous other SAE existing or under development voluntary industry standards and recommended practices for heavy-duty vehicle electrification safety[485] (e.g., SAE J2910, J1654, J1673, J1742, J1797, J2344, J2464, J2758, J 2936, J2990.)

[483] Same as 470, and see postings at www.nhtsa.gov/About+NHTSA/Press+Releases/NHTSA+Statement+on+Conclusion+of+Chevy+Volt+Investigation

[484] See http://standards.sae.org/j2929_201102/ for "Electric and Hybrid Vehicle Propulsion Battery System Safety Standard - Lithium-based Rechargeable Cells" J2929, 2011-02-18
See J2929,2011-02-18 "Electric and Hybrid Vehicle Propulsion Battery System Safety Standard - Lithium-based Rechargeable Cells" at http://standards.sae.org/j2929_201102/

[485] See www.sae.org/standardsdev/vehicleelectrification.htm and http://ev.sae.org/standards/power-propulsion/items/

5 REGULATORY BARRIERS ANALYSIS

5.1 Introduction

A review of the existing DOT multi-modal (NHTSA, FHWA, and FMCSA) regulatory framework was conducted to evaluate the potential impacts of state, Federal, and NAFTA regulations on the adoption of fuel efficiency-improving technologies and alternative fuels on commercial MD/HDVs. The focus was on identifying any regulatory barriers to rapid deployment of FE technologies and alternative fuels in the MD/HDV fleet, and a comprehensive list of regulations affecting FE adoption is summarized in Table 5-1. This regulatory review and analysis included a review only of technologies with identified relevant regulatory (both Federal and state) barriers:

- Impacts on effective HD vehicle size and weight, cargo volume capacity, number of vehicles on road, infrastructure wear and tear;
- Aerodynamic technologies that may exceed applicable trailer length regulations;[486]
- Longer combination vehicles that may exceed applicable vehicle length regulations;
- Implications of Federal and State inch-width pavement weight laws for using wide based tires on non-tandem axle combination trucks;[487]
- National electric and natural gas transmission code standards, if applicable;[488]
- Potential conflicts with applicable safety equipment regulations raised by replacing side mirrors with cameras.[489]

The NACFE report on "Barriers to the Increased Adoption of Fuel Efficiency Technologies in the North American On-Road Freight Sector"[490] focused primarily on market barriers, reporting only a few comments on incentives and barriers associated with existing and emerging regulations, such as the NHTSA and EPA fuel efficiency and GHG rule and the CARB tractor-trailer GHG Rule. Similarly, the CalHEAT report[491] on market barriers to truck industry adoption of FE technologies and alt-fuels mentioned in Sec.1 did not address remaining regulatory barriers.

[486] Transport Canada. 2009a. Aerodynamic Trailer Skirts www.tc.gc.ca/eng/programs/environment-ecofreight-road-aerodynamic-trailer-skirts-2540.htm
[487] EPA. 2012. Low Rolling Resistance Tires A Glance at Clean Freight Strategies www.epa.gov/smartway/documents/partnership/trucks/partnership/techsheets-truck/EPA-420-F10-041.pdf
[488] NREL. 2010a. Electric Vehicle and Infrastructure Codes and Standards Citations www.afdc.energy.gov/pdfs/48605.pdf, NREL. 2010b. Natural Gas Vehicle and Infrastructure Codes and Standards Citations www.afdc.energy.gov/pdfs/48611.pdf
[489] Florida Department of Transportation. 2010. Evaluation of Camera-Based Systems to Reduce Transit Bus Side Collisions www.nctr.usf.edu/pdf/77905.pdf, Wierwille, W. W., Schaudt, W. A., Blanco, M., Alden, A. S., & Hanowski, R. J. 2011. Enhanced Camera/Video Imaging Systems (E-C/VISs) For Heavy Vehicles: Final Report www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811483.pdf
[490] See NACFE-ICCT 2013 report at www.theicct.org/sites/default/files/publications/ICCT-NACFE-CSS_Barriers_Report_Final_20130722.pdf
[491] See CalHEAT "Market Barriers And Opportunities For Alternative Fuel-Hybrid Systems" June 2013 at www.calstart.org/Libraries/CalHEAT_2013_Documents_Presentations/CalHEAT_Market_Barriers_and_Opportunities_for_Alternative_Fuel-Hybrid_Systems.sflb.ashx

The DOE/AFDC Fuels and Vehicles posts resources on Federal and State laws and regulations that incentivize the vehicle hybridization and electrification[492] and alt-fuels adoption legal incentives by state,[493] but an analysis of regulatory barriers is essential for their removal.

The 2002 FMCSA NAFTA rules that apply to Mexico and Canada trucks and buses arriving at border crossings and operating in the United States[494] are enforcing safety regulations that apply to the U.S. truck fleet, but they address neither FE technologies nor alternative fuels. A recent Congressional Research Service (CRS) review of Federal freight policy and legislative initiatives[495] mentions that the Moving Ahead for Progress in the 21st Century (MAP-21) legislation instructed DOT to perform a study of existing truck size and weight (TS&W) limits.[496] The goal is to update Federal TS&W regulations applicable to the National Network of highways and arterial access roads (23 CFR 658) and to harmonize the current patchwork of State regulations discussed below and listed in Table 5-1. Federal TS&W limits apply only to the 209,000 miles of interstate highways and principal access arterials, whereas States regulate and restrict LCVs operations on all other highways and roads.

Below in Sections 5.2-5.9, are discussed potential regulatory barriers to the adoption of specific FE technologies. OMB Circular A-119 requires Federal agencies to adopt and adapt applicable voluntary consensus standards, where applicable, as a cost-effective alternative to rulemaking.[497] The Society of Automotive Engineers (SAE), American National Standards Institute (ANSI), NFPA and other standards-developing organizations (SDOs) develop the safety standards and recommended practices for existing and emerging FE technologies and alternative fueled vehicles that are voluntarily adopted by OEMs and vehicle fleet owners and operators. These voluntary industry standards and guidelines may provide sufficient assurance of safe operability of MD/HDVs equipped with FE technologies and using alternative fuels, without requiring additional regulatory development.

5.2 Adoption of Alternative Clean Fuels

There are no major regulatory barriers for the adoption of CNG, LNG, or biodiesel as fuels in MD/HDV fleets. Indeed, there are more Federal and State regulatory and economic/tax incentives for adopting cleaner alternative fuels than barriers to adoption. The DOE Alternative Fuels Data Center has compiled summaries of Federal and State laws and incentives by type of fuel and/or technology.[498] The EPA's Renewable Fuel Standards and State regulations and tax incentives for technology or fuel adoption to improve air quality (e.g., idle reduction equipment) are compiled and posted by the Transportation Environmental Resource Center.[499]

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492 See www.afdc.energy.gov/fuels/laws/ELEC/US
493 See www.afdc.energy.gov/laws and database on State incentives at www.dsireusa.org/
494 FMCSA. 2007b. NAFTA Demonstration Project www.fmcsa.dot.gov/intl-programs/nafta-rules/new-mexrule.htm
495 Frittelli, J. 2012. Federal Freight Policy: An Overview www.fas.org/sgp/crs/misc//R42764.pdf
496 FHWA. 2012b. Moving Ahead for Progress in the 21st Century Act (MAP-21) www.fhwa.dot.gov/map21/summaryinfo.cfm
497 Composites World. 2007. New hybrid electric bus takes advantage of composites www.compositesworld.com/articles/new-hybrid-electric-bus-takes-advantage-of-composites
498 DOE Alternative Fuels Data Center. 2013a. Laws and Incentives www.afdc.energy.gov/laws/search
499 Tranportation Environmental Resource Center. 2013. Tranportation Environmental Resource Center List of State Regulations and Incentives for Alternative Fuels www.tercenter.org/pages/altfuelMA.htm

5.3 Hybridization and Electrification

5.3.1 Electric Drivetrain

Minimum speed limits may pose a challenge for all-electric technologies as MDHD vehicles equipped with electric drive systems may under some circumstances be unable to travel fast enough to meet minimum speed limits on high grade inclines, per SME input in Section 3.2.2. There are no Federal regulations establishing minimum speed limits, so each State regulates this independently.[500] E-truck routes have been voluntarily "certified" by fleet managers for safe operation.

5.3.2 Hybrid Hydraulic Drivetrain

Excess weight added by hybrid hydraulic drivetrains may cause MD/HDVs to exceed applicable weight regulations. National weight standards apply to all commercial vehicle operations on the Interstate Highway System. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) froze the maximum weight of vehicles on the Interstate System at 20,000 pounds per single axle, 34,000 pounds per tandem axle, and 80,000 pounds overall gross weight, or at the gross weight limit actually and lawfully in effect for such vehicles in a State on June 1, 1991 (in cases where that limit exceeds 80,000 pounds). Lower weight limits may be enforced where derived by a bridge formula. States are not allowed to set weight limits on the interstate highway system at less than the Federal weight limits.[501]

Beyond the Interstate System, States have the flexibility to set their own weight limits, but Colorado is the only State to provide a weight exemption (of 1,000 pounds) for hybrid vehicles off the Interstate system, as described in the Colorado Revised Statutes 25-7-106.8 and 42-4-508.

5.4 ITS and Telematics

There are no major regulatory barriers identified for the adoption of ITS or telematics for MD/HDVs, as seen in Table 5-1. As discussed in Sections 2.4 and 3.2.3, there are both potential energy savings and efficiency benefits to their fleet-wide adoption. There may be barriers to adoption of telematics technologies by fleet owners and operators related to concerns with system and operational costs, or with drivers' privacy protection[502] , when fleet managers monitor the safety and efficiency performance of both assets and drivers that use GPS and ITS-enabled devices. For instance, the FMCSA 2010 and 2011 NPRM related to Electronic On-Board Recorders (EOBR) requirements for CMV operators and carriers faced litigation and was withdrawn and later modified in an MPRM requiring Electronic Logging Devices (ELD) and

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[500] Insurance Institute for Highway Safety. 2013. State Speed Limits www.iihs.org/laws/speedlimits.aspx

[501] Vaidya, U. 2012. GATE Center of Excellence at UAB for Lightweight Materials and Manufacturing for Automotive Technologies www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/technology_integration/ti026_vaidya_2012_p.pdf

[502] See www.worktruckonline.com/channel/safety-accident-management/article/story/2009/08/beware-the-legal-pitfalls-in-telematics-monitoring-of-employee-drivers.aspx

Hours of Service (HOS) documentation to address concerns with potential drivers' privacy and harassment issues.[503]

5.5 *Human Factors and Operations*

5.5.1 Idle Reduction

Adoption of idle reduction technologies by MD/HDVs[504] is driven by compliance requirements with EPA Clean Air regulations, as well as with State and local mandates. There are many anti-idling technology options verified by the EPA SmartWay program,[505] which applies to certification of new engines, rather than the whole vehicle. Excess weight from idle reduction technologies may cause MD/HDVs to exceed applicable weight regulations (for more detail on weight regulations, see Section 6.3.2). States may (but are not required to) allow MD/HDVs equipped with idle reduction technology to exceed the maximum gross vehicle weight limit and the axle weight limit by up to 550 pounds to compensate for the additional weight of the idle reduction technology.[506]

Most States have opted to allow weight exemptions for idle reduction technology. However, California, Hawaii, Kentucky, North Carolina, Rhode Island, and Tennessee and the District of Columbia do not allow weight exemptions. Most States and many cities limit the amount of time that MD/HDVs can idle, although the regulations in Table 6-1 do not address a specific anti-idling technology.

5.5.2 Speed limiters

There were no identified regulatory barriers preventing adoption of speed limiters for MD/HDVs. NHTSA published a notice in the Federal Register on January 3, 2011, granting petitions for rulemaking for an Engine Control Module Speed Limiter Device.[507]

5.6 *Longer Combination Vehicles and Truck Size and Weight Limits*

Existing vehicle length and weight regulations may be limiting the adoption of LCVs. Regulatory restrictions for LCVs vary on a State-by-State basis, and this heterogeneity is preserved by Federal law. In 1991 ISTEA froze maximum weight and length limits for each State at their 1991 values.[508] The Federal Highway Administration Office of Freight Management issued in December 2012 a notice soliciting bids for a new study on specific areas of Federal TS&W limits, their operation and their impacts, responding to a mandate in the MAP-

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503 See www.fmcsa.dot.gov/regulations/rulemaking/2011-8789 and www.fmcsa.dot.gov/regulations/rulemaking/2014-11244

504 See www.afdc.energy.gov/conserve/idle_reduction_heavy.html

505 See www.epa.gov/smartway/forpartners/technology.htm#tabs-4

506 Ibid.

507 NHTSA. 2011a. Federal Motor Vehicle Safety Standard; Engine Control Module Speed Limiter Device https://www.federalregister.gov/articles/2011/01/03/2010-33057/federal-motor-vehicle-safety-standard-engine-control-module-speed-limiter-device, Transport Canada. 2009a. Aerodynamic Trailer Skirts www.tc.gc.ca/eng/programs/environment-ecofreight-road-aerodynamic-trailer-skirts-2540.htm

508 Frittelli, J. 2012. Federal Freight Policy: An Overview www.fas.org/sgp/crs/misc//R42764.pdf

21 legislation.[509] This requirement to further study the issue and complete the study by November 2014 was an outcome of contested proposals to allow six-axle truck/trailer configurations to gross 97,000 pounds.

As mentioned, ISTEA enforced a freeze limiting the use of the longer, heavier double- and triple-trailer combinations to those States in which they were already operating in 1991.[510] Specifically, ISTEA imposed freezes on: 1) the maximum weight of LCVs, which consist of any combination of a truck tractor and two or more trailers or semitrailers which operate on the Interstate System at a gross weight over 80,000 pounds; and (2) the overall length of the cargo carrying units of combination vehicles with two or more such units where one or both exceed 28.5 feet in length on the National Network. The maximum weight of LCVs and the maximum length of the cargo carrying units of combination vehicles is the weight or length in actual and legal operation in a State on June 1, 1991.[511]

Weight limits governing trucking operations across the two international U.S. borders are very different. In crossing to Canada, all but one crossing for NHS highways have a GVW limit of more than 99,000 pounds; 9 of the 11 Interstate crossings have GVW limits of more than 105,000 pounds. In crossing to Mexico, all four Interstate crossings are limited to a GVW of 80,000 pounds, and six of nine other crossings on the NHS have a GVW of 84,000 pounds (with a permit from Texas).[512] Harmonized operational restrictions, including route designations for LCVs, would help to foster their adoption. Figure 5-1 shows the current regulatory environment for LCVs in the United States. The existing environment for LCV operation is a State-by-State patchwork.

Recent legislative initiatives include the 2011 two competing bills in Congress addressing TS&W limits, neither of which became law:[513]

- The Safe and Efficient Transportation Act (HR763, S747) to allow States to increase the weight limit from 80,000 lbs. to 97,000 with an extra axle and extra wheels, when appropriate.
- The Safe Highways and Infrastructure Protection Act (HR1574, S876) to prohibit any weight limit increase and would extend Federal size and weight limits to the entire National Highway System.
- In February 2013 the Safe and Efficient Transportation Act bill was introduced in the House (H.R. 612) to allow States to increase Interstate truck weights to 97,000 pounds, and require LCV tractor-trailers have a sixth axle to decrease per-tire weight and improve braking.

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509 FHWA. 2012a. MAP-21 Freight Provisions www.fhwa.dot.gov/planning/freight_planning/talking_freight/nov282012transcript.cfm

510 FHWA. 2000. Comprehensive Truck Size and Weight Study Volume 2, Chapter 3 www.fhwa.dot.gov/reports/tswstudy/Vol2-Chapter3.pdf

511 Vaidya, U. 2012. GATE Center of Excellence at UAB for Lightweight Materials and Manufacturing for Automotive Technologies www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/technology_integration/ti026_vaidya_2012_p.pdf

512 FHWA. 2000. Comprehensive Truck Size and Weight Study Volume 2, Chapter 3 www.fhwa.dot.gov/reports/tswstudy/Vol2-Chapter3.pdf

513 Frittelli, J. 2012. Federal Freight Policy: An Overview www.fas.org/sgp/crs/misc//R42764.pdf

- In May 2013 the Safe Highways and Infrastructure Preservation Act of 2013 (SHIPA, H.R. 1906 and S. 880) legislation[514] was introduced in Congress, that would extend the current limit of 80,000 pounds on five axles in 53-foot trailers to the entire 220,000-mile National Highway System, beyond the current 44,000 miles of interstates. SHIPA is intended to close a loophole used by States to allow longer, heavier trucks on certain Federally funded roadways. Both competing bills are still pending.

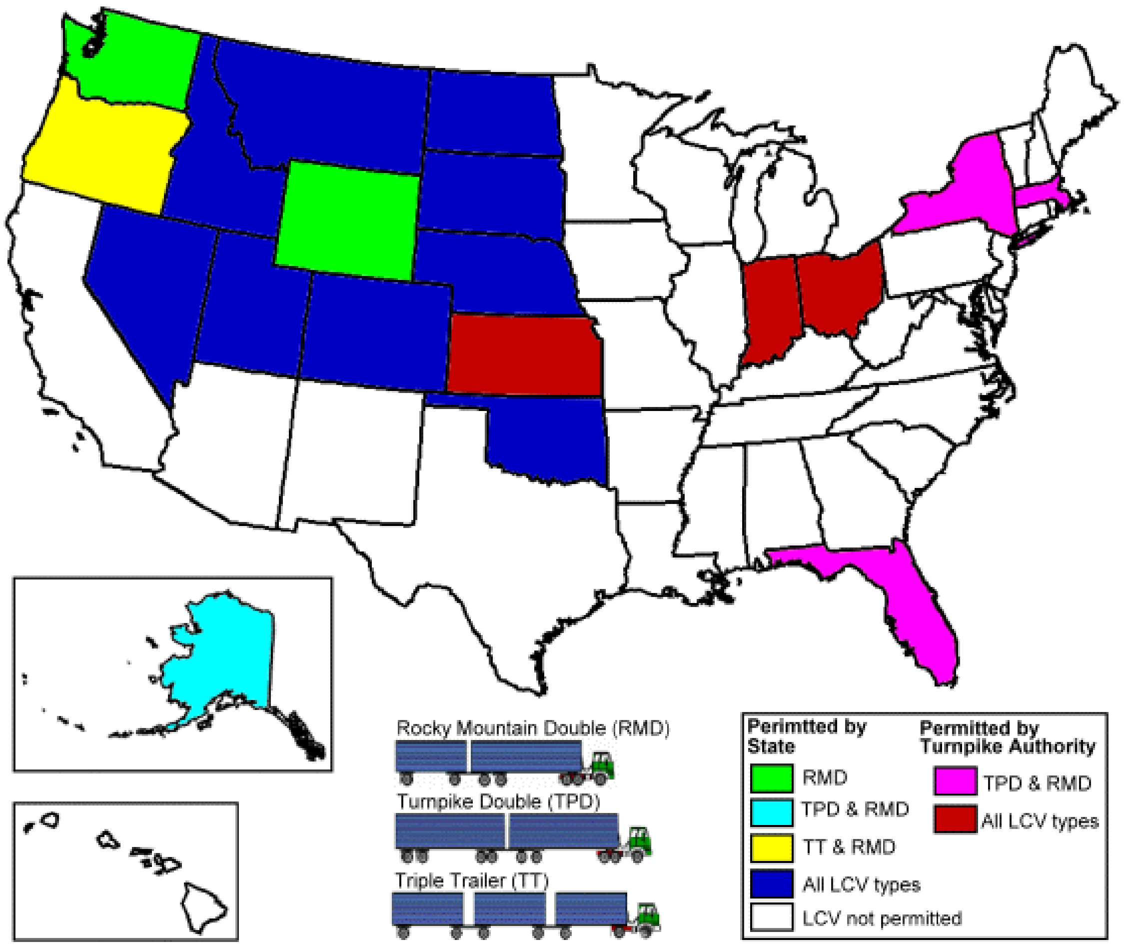

Figure 5-1: Regulatory Environment for Longer Combination Vehicles in the United States

5.7 *Tire Technologies*

5.7.1 Tire Pressure Management Systems and Automatic Tire Inflation Systems

There are no major regulatory barriers for the adoption of TPMS or ATIS for MD/HDVs. The NHTSA regulations in 49 CFR Parts 571.138 and 585 (FMVSS 138) require TPMS for new vehicles under 10,000 pounds (LDVs) and stipulate that the system must include a warning

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[514] See www.truckingalliance.org/news/lautenberg-introduces-bill-to-restrict-truck-size-and-weight

signal to the operator when the pressure is outside a certain pressure range. MD/HDVs are not covered by the NHTSA regulations.

5.7.2 Single Wide Tires

Single wide tires meet the inch-width weight requirements for all States for dual axles but are restricted in certain States to 17,500 lbs. on a single axle at 500 lbs./inch width limit. They are disallowed on single axle positions on certain double and triple combination vehicles.[515] The ATA has a spreadsheet available of the latest regulations for some States that limit "single tire" use and is working with these States to clarify regulations and resolve the limitations.[516]

5.7.3 Low Rolling Resistance Tires

By statute, NHTSA's Tire Fuel Efficiency Consumer Information Program (TFECIP) only rates the fuel efficiency (i.e., rolling resistance), safety (i.e., wet traction), and durability (i.e., tread wear life) of passenger car replacement tires. Some have claimed[517] that low rolling resistance tires may increase stopping distances, and would therefore conflict with corresponding NHTSA tire safety standards (FMVSS 119)[518] requirements, which apply to single wide tires. Lab and road testing on LRR performance on packed snow traction concluded that "the current generation of SmartWay verified LRR tires can offer a similar level of snow traction performance as non-SmartWay verified tires, while reducing fuel consumption and emissions."

As mentioned in section 2.7.3, a NHTSA 2009 study of low and standard rolling resistance tires for light-duty vehicles demonstrated a strong and significant correlation between lower rolling resistance and increased wet slide, or the propensity to lose traction on wet road surfaces. However, this was most significant for vehicles without Anti-lock Braking Systems (ABS). For newer vehicles with ABS or electronic stability control (ESC) systems, the tradeoff was found to be less significant.[519] The study did not address MD/HDVs, and prior findings may therefore have limited applicability.

ABS has been required by NHTSA on all trucks and buses since 1997-1999 per FMVSS 121, which would suggest that it is unlikely that low rolling resistance tires would conflict with the maximum stopping distance for MD/HDV vehicles specified within that regulation. However, the 2009 study did not examine MD/HDVs and the effects on stopping distance may vary based

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[515]New Generation of Wide-Base Tires: Impact on Trucking Operations, Environment, and Pavements, 2008, TRB at http://trid.trb.org/view.aspx?id=802211

[516] Goodyear Truck Tires. 2013. Standards & Regulations www.goodyeartrucktires.com/pdf/resources/service-manual/Retread_S13_V.pdf

[517] Cited in Transport Canada Nov. 2012 study "Test Report Packed Snow Performance of Low Rolling Resistance Class 8 Heavy Truck Tires" at www.tc.gc.ca/media/documents/programs/nrc_test_report-packed_snow_performance_eng.pdf

[518] See FMVSS 119, New Pneumatic Tires for Vehicles Other Than Passenger Cars, www.nhtsa.gov/cars/rules/import/FMVSS/#SN119

[519] Evans, L. R., MacIsaac, J. D., Harris, J. R., Yates, K., Dudek, W., Holmes, J., Popio, J., Rice, D., & Salaani, M. K. 2009. NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 2 – Effects of Tire Rolling Resistance Levels on Traction, Treadwear, and Vehicle Fuel Economy www.nhtsa.gov/DOT/NHTSA/NVS/Vehicle%20Research%20&%20Test%20Center%20%28VRTC%29/ca/Tires/811154.pdf

on vehicle size and weight. Existing truck stopping distance requirements (49 CFR 571.121), as well as proposed ESC[520] standards and a grant of petition for rulemaking on speed limiters[521] could create effective countermeasures for the potential degradation of braking or vehicle handling performance.

5.8 Aerodynamic Components

Aerodynamic technologies may conflict with applicable length and width regulations. However, according to FHWA regulations in 23 CFR Part 658.16 and Appendix D (see Table 5-1), aerodynamic devices that do not extend more than 5 feet beyond the rear of the vehicle are exempt from length limits, provided they do not have the strength, rigidity, or mass to damage a vehicle or injure a passenger and do not obscure tail lamps, turn signals, marker lamps, identification lamps, or any other required safety devices.[522]

Replacing side mirrors with cameras may conflict with applicable safety equipment regulations. NHTSA regulations in 49 CFR 571.111 require mirrors and do not include wording to allow cameras as an alternative. According to this regulation each multipurpose passenger vehicle, bus, or truck with a GVWR of more than 4,536 kilograms shall:

> "Have outside mirrors of unit magnification, each with not less than 323 square centimeters of reflective surface, installed with stable supports on both sides of the vehicle. The mirrors shall be located so as to provide the driver a view to the rear along both sides of the vehicle and shall be adjustable both in the horizontal and vertical directions to view the rearward scene."

5.9 Lightweight Components

The NHTSA FMVSS 121, Air Brake Systems[523] regulation mandates 250-310 foot maximum stopping distances for heavy trucks at 60 mph. To provide more stopping power and counteract fade at high temperatures, brake manufacturers have increased the size and weight of their drum systems. However, one of several options for vehicle weight reduction is for brake systems to become smaller and lighter, aiding manufacturers in meeting fuel efficiency standards. Reducing weight and handling more work in order to meet required stopping distances are the dual forces driving the adoption of air-disc brakes. This does not create an actual adoption barrier but it is possible that future, more stringent fuel efficiency regulations could lead to potential conflict between these two purposes.

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520 https://www.Federalregister.gov/articles/2012/05/23/2012-12212/Federal-motor-vehicle-safety-standards-electronic-stability-control-systems-for-heavy-vehicles

521 https://www.Federalregister.gov/articles/2011/01/03/2010-33057/Federal-motor-vehicle-safety-standard-engine-control-module-speed-limiter-device.

522 Vaidya, U. 2012. GATE Center of Excellence at UAB for Lightweight Materials and Manufacturing for Automotive Technologies
www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/technology_integration/ti026_vaidya_2012_p.pdf
www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/technology_integration/ti026_vaidya_2012_p.pdf

523 www.nhtsa.gov/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/121_Stopping_Distance_FR.pdf

5.10 Findings and Conclusions Regarding Regulatory Barriers

There are few regulatory barriers to the adoption of FE technologies for MD/HDVs. Table 5-1 lists various categories of FE technologies and discusses the potential regulatory barriers that were investigated in this report. In each row a green "no" indicates that there are no documented regulatory barriers and a red "yes" indicates that there may be a barrier or conflict.

Most of the potential barriers relate in some way to truck size and weight (TS&W) regulations. This may have implications for hybrid-electric and hybrid-hydraulic technologies, battery-electric vehicles, idle reduction technologies, and LCVs. Size and weight regulations vary from State to State and the restrictions of one State may have indirect consequences on the use of FE technologies in surrounding States since truck operators must be compliant with regulations at every stage along a given route. In the case of LCVs, the Intermodal Surface Transportation Efficiency Act (ISTEA) preserved the heterogeneity of State regulations by enforcing a freeze limiting the use of the longer, heavier double- and triple-trailer combinations to those States in which they were already operating in 1991 (see Section 5.6).[524]

However, in December 2012 the FHWA Office of Freight Management issued a notice soliciting bids for a new study on specific areas of Federal TS&W limits, their operation and their impacts, in response to a mandate in the MAP-21 legislation.[525] This requirement for further study was an outcome of contested proposals to allow six-axle truck/trailer configurations to gross 97,000 pounds. After further study FHWA may update the regulations on LCVs. A regulatory barrier for future consideration relates to the additional weight of some future (Phase 2) MD/HDV technologies. The need for their proximity to the engine (e.g., waste heat recovery, turbo-compounding) may bump tractor weights up above the 12,000 lb. front axle weight limit. This challenge was suggested in some DOE sponsored SuperTruck projects.[526]

Another potential regulatory barrier relates to certain restrictions on the use of single wide tires. These limitations similarly vary from State to state. Organizations such as the ATA are working to resolve inconsistencies and to promote harmonized regulations across State boundaries for single wide tires. Also, as described in Section 5.8, replacing side mirrors with cameras may conflict with applicable safety equipment regulations. The NHTSA regulations in 49 CFR 571.111 appear to require mirrors and do not include language to allow cameras as an alternative.

There are a few areas where pending or proposed regulatory action may influence the adoption of FE technologies. For instance, NHTSA has begun a rulemaking process to consider speed-limiting devices on heavy-duty trucks, as described in Section 2.5.1.3. In addition, FMCSA will

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[524] FHWA. 2000. Comprehensive Truck Size and Weight Study Volume 2, Chapter 3 www.fhwa.dot.gov/reports/tswstudy/Vol2-Chapter3.pdf

[525] FHWA. 2012a. MAP-21 Freight Provisions www.fhwa.dot.gov/planning/freight_planning/talking_freight/nov282012transcript.cfm

[526] See Navistar project weight per axle at www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/veh_sys_sim/vss064_jadin_2012_o.pdf

consider updated regulations regarding inspections of NGVs[527] and has conducted research to identify relevant safety issues raised by stakeholders.[528]

Finally, OMB Circular A-119 requires Federal agencies to adopt and adapt applicable voluntary consensus standards, where applicable, as a cost-effective alternative to rulemaking.[529] Consensus standards by organizations such as SAE, ANSI, NFPA and others may provide sufficient assurance of safe operability of MDHDVs equipped with FE technologies and using alternative fuels.

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[527] FMCSA. 2012a. Natural Gas Systems, Final Report, Kwan, Q. 2012. Safety Considerations Related to Commercial Vehicles Using Natural Gas www1.eere.energy.gov/cleancities/pdfs/ngvtf12_kwan.pdf

[528] Transport Canada. 2009b. Summary Report - Assessment of a Heavy Truck Speed Limiter Requirement in Canada www.tc.gc.ca/eng/roadsafety/tp-tp14808-menu-370.htm

[529] Composites World. 2007. New hybrid electric bus takes advantage of composites www.compositesworld.com/articles/new-hybrid-electric-bus-takes-advantage-of-composites, Office of Management and Budget. 1998. Circular No. A-119 Revised www.whitehouse.gov/omb/circulars_a119

Table 5-1: Summary of Potential Regulatory Barriers for the Adoption of MD/HDV Fuel Efficiency Technologies

Chapter index	FE technology	Potential issue/conflict with existing regulations	Regulatory Entity	Regulation's full name	Potential Barrier?	Description
2.8.3	Aerodynamic components	Aerodynamic technologies may exceed applicable trailer length regulations.	FHWA	23 CFR Part 658.16 - Length limit exemptions. (and appendix D to 23 CFR 658)-	No	Aerodynamic devices that do not extend more than 5 feet beyond the rear of the vehicle are exempt from length limits, provided they do not have the strength, rigidity, or mass to damage a vehicle or injure a passenger and do not obscure tail lamps, turn signals, marker lamps, identification lamps, or any other required safety devices.
3.2.8	Aerodynamic components	Replacing side mirrors with cameras may conflict with applicable safety equipment regulations	FHWA	23 CFR Part 658.16 (and appendix D to 23 CFR 658)	No	FHWA: Certain devices are allowed to extend beyond the width limit, including rear-view mirrors, so switching to cameras will not alter the effective width limit.
3.2.8	Aerodynamic components	Replacing side mirrors with cameras may conflict with applicable safety equipment regulations	NHTSA	49 CFR 571.111	Yes	NHTSA: Regulation 571 appears to require mirrors and does not include wording to allow cameras as an alternative.
2.2.2.3	Biodiesel	None			No	
2.2.1.3, 5.2.1.1	CNG	None			No	
3.2.2	Hybrid/electric	MDHD vehicles may not be able to travel fast enough to meet minimum speed limits on high grade inclines.	State		No	There are no Federal regulations establishing minimum speed limits. Each State regulates this independently. E-truck routes have been voluntarily "certified" by fleet managers for safe operation.
3.2.2	Hybrid/hydraulic	Excess weight added by a series HH drivetrain may exceed applicable vehicle weight regulations.	FHWA	23 CFR 658.17, 23 CFR 658.23	Yes	National weight standards apply to all commercial vehicle operations on the Interstate Highway System. ISTEA froze the weights of truck tractors with two or more trailing units operating above 80,000 pounds on the Interstate System at the weight limits actually and lawfully in effect for such vehicles in a State on June 1, 1991. FHWA issued a final rule on June 13, 1994.
3.2.2	Hybrid/hydraulic	Excess weight added by a series HH drivetrain may exceed applicable vehicle weight regulations.	State	Colorado Revised Statutes 25-7-106.8 and 42-4-508	Yes	Only one state, Colorado, provides a 1,000 lb. vehicle weight exemption for hybrid vehicles off the Interstate system.
2.5.2.3, 3.2.5	Idle reduction technologies	Excess weight from idle reduction technology may exceed applicable vehicle weight regulations.	FHWA	Federal: Public Law 112-141 (MAP-21) and 23 U.S. Code 127(a)(12)	No	Idle Reduction Technology Weight Exemption: States may (but are not required to) allow heavy-duty vehicles equipped with idle reduction technology to exceed the maximum gross vehicle weight limit and the axle weight limit by up to 550 pounds (lbs.) to compensate for the additional weight of the idle reduction technology.

Chapter index	FE technology	Potential issue/conflict with existing regulations	Regulatory Entity	Regulation's full name	Potential Barrier?	Description
2.5.2.3, 3.2.5	Idle reduction technologies	Extra weight from incorporation of idle reduction technology may exceed applicable vehicle weight regulations.	State		Yes	Most States allow heavy-duty vehicles equipped with idle reduction technology to exceed the maximum gross vehicle weight limit and the axle weight limit by up to 550 pounds (lbs.) to compensate for the additional weight of the idle reduction technology. However, six States (California, Hawaii, Kentucky, North Carolina, Rhode Island, Tennessee) and the District of Columbia do not allow weight exemptions. Most States and many cities limit the amount of time that MD/HDVs can idle, although 49-State and local regulations do not specifically address anti-idling technology.
2.4.1.3	ITS/telematics	None			No	
3.2.9, 4.2.3	Lightweighting materials	Stopping distance regulations could conflict with the desire to decrease weight	NHTSA	FMVSS 121: Air Brake Systems 49 CFR Part 571	Yes	NHTSA FMVSS 121 mandates 250-310 foot maximum stopping distances for heavy trucks at 60 mph. To provide more stopping power and counteract fade at high temperatures, brake makers have increased the size and weight of their drum systems. However, these design changes may decrease fuel efficiency instead of aiding OEMs in meeting the new GHG-FE rules. There is now greater demand for brake systems that are smaller and lighter yet still handle more work; this is driving the adoption of air-disc brakes.
2.2.1.4	LNG	None			No	
2.6.3	Longer combination vehicles	Longer combination vehicles may exceed applicable vehicle length regulations.	FHWA	23 CFR 658.9, 23 CFR 658.11, and Appendix A to 23 CFR Part 658	Yes	ISTEA imposed freezes on: 1) on the maximum weight of LCVs, which consist of any combination of a truck tractor and two or more trailers or semitrailers which operate on the Interstate System at a gross weight over 80,000 pounds; and (2) on the overall length of the cargo carrying units of combination vehicles with two or more such units where one or both exceed 28.5 feet in length on the National Network. The maximum weight of LCVs and the maximum length of the cargo carrying units of combination vehicles is the weight or length in actual and legal operation in a State on June 1, 1991. Therefore, except for within the grandfathered States, LCVs cannot operate on Interstate highways. There is a patchwork of national (FHWA), international (Canamex), and State-based LCV restrictions. Harmonized operational restrictions, including route designations for LCVs, should be considered.
2.6.3	Longer combination vehicles	Longer combination vehicles may exceed applicable vehicle length regulations.	State		Yes	Some States do not allow LCVs (See map included in chapter 6 text).

Chapter index	FE technology	Potential issue/conflict with existing regulations	Regulatory Entity	Regulation's full name	Potential Barrier?	Description
2.6.3, 4.2.5	Longer combination vehicles	Longer combination vehicles may exceed applicable vehicle weight regulations.	FHWA	23 CFR 658.23 LCV freeze (ISTEA freeze), including Appendix C (grandfathered state-wise LCV limits)	Yes	ISTEA imposed freezes on: 1) on the maximum weight of LCVs, which consist of any combination of a truck tractor and two or more trailers or semitrailers which operate on the Interstate System at a gross weight over 80,000 pounds; and (2) on the overall length of the cargo carrying units of combination vehicles with two or more such units where one or both exceed 28.5 feet in length on the National Network. The maximum weight of LCVs and the maximum length of the cargo carrying units of combination vehicles is the weight or length in actual and legal operation in a State on June 1, 1991.
2.7.3.3, 4.2.4, 3.2.7	Low rolling resistance tires	Low rolling resistance tires may conflict with stopping distance regulations.	NHTSA	49 CFR Part 575 FMVSS 121 - Air Brake Systems - Trucks, Buses, and Trailers	No	ABS has been required by NHTSA on all trucks and buses since 1997-1999 per FMVSS 121. The average age of Class 8 tractors, which stand to benefit the most from LRR tires, is approximately 9 years. FMVSS 121 also specifies maximum stopping distance for air brake systems on MDHDVs, regardless of tires. Potential countermeasures to degradation of braking or vehicle handling performance include electronic stability control and speed limiter implementation.
2.7.3.3, 5.2.4, 3.2.7	Low rolling resistance tires	Low rolling resistance tires may conflict with stopping distance regulations.	FMCSA	49 CFR 393.52(a)(3) FMCSA brake performance.	No	FMCSA regulates the maximum braking distance at 20 mph for GVW greater than 10,000 lbs. Potential countermeasures to degradation of braking or vehicle handling performance include electronic stability control and speed limiter implementation.
2.7.2.3	Single-wide tires	Inch-width pavement weight laws may preclude the use of wide based tires on non-tandem axle combination trucks.	FHWA		No	National weight standards apply to commercial vehicle operations on the Interstate Highway System, an approximately 40,000-mile system of limited access, divided highways that spans the Nation. Off the Interstate Highway System, States may set their own commercial vehicle weight standards.
2.7.2.3	Single wide tires	State inch-width pavement weight laws may preclude the use of wide based tires on non-tandem axle combination trucks.	State		Yes	Single wide tires meet the inch width-weight limits for all States, but are restricted in certain States to 17,500 lbs. on a single axle at 500 lbs./inch width limit, and are disallowed on single axle positions on certain double and triple combination vehicles (from a white paper developed by the American Trucking Association). The American Trucking Association has a spreadsheet available of the latest regulations for some States that limit "single tire" use. Work is ongoing with these States to clarify regulations and resolve the limitations.

Chapter index	FE technology	Potential issue/conflict with existing regulations	Regulatory Entity	Regulation's full name	Potential Barrier?	Description
2.5.1.3, 3.2.4	Speed limiters	None			No	NHTSA plans to publish a notice of proposed rulemaking in late 2013.[530]
2.7.1.3	TPMS/ATIS	None	NHTSA	49 CFR Parts 571.138 and 585: FMVSS 138 Tire Pressure Monitoring Systems	No	NHTSA: TPMS is required for new vehicles under 10,000 lbs., and it must include a warning signal to the operator when the pressure is outside a certain pressure range. MDHDVs are not covered by the regulation.

[530] See "Truck Speed Limiter Proposal Returned to NHTSA," www.truckinginfo.com/channel/safety-compliance/news/story/2013/05/truck-speed-limiter-proposal-returned-to-nhtsa.aspx?prestitial=1

6 CONCLUSIONS AND RECOMMENDATIONS

The relevant safety findings from the literature review, summarized in Chapter 2, were complemented by inputs from focused interviews with experienced SMEs regarding the rapidly expanding use of alternative fuels, as discussed in Chapter 3. A cross-cutting measure for the safe deployment of new FE technologies and fuels is to provide improved CMV driver training. Safety concerns identified from the literature review and SMEs' inputs can be prevented or mitigated by complying with applicable regulations, and safety standards and industry best practices and can be addressed by evolving ITS technologies and collision prevention devices. The key finding from this study is that there are no major safety hazards preventing the adoption of FE technologies or the increased use of alternative fuels and vehicle electrification by the Nation's MD/HDV fleet in order to achieve environmental and economic benefits while complying with NHTS/EPA regulations.

Chapter 2 safety-relevant fuel- or technology-specific specific findings include:

- Both CNG- and LNG-powered vehicles present potential hazards, and call for well-known engineering and process controls to assure safe operability and crashworthiness. However, based on the reported incident rates of NGVs and the experiences of adopting fleets, it appears that NGVs can be operated at least as safely as diesel MD/HDVs. Using natural gas instead of diesel fuel may help fleets comply with the MD/HD greenhouse gas rules that require up to 20 percent emissions reduction by 2018.
- There are no safety contraindications to the large scale fleet adoption of CNG or LNG fueled heavy-duty trucks and buses, and there is ample experience with the safe operation of large public transit fleets. Voluntary industry standards and best practices suffice for safety assurance, though improved training of CMV operators and maintenance staff is needed to ensure natural gas safety of equipment and operating procedures. Sound design, manufacture and inspection of natural gas storage tanks will further reduce the potential for leaks, tank ruptures, fires, and explosions.
- Biodiesel blends used as drop-in fuels have presented some operational safety concerns depending on blending fraction, such as material compatibility, bio-fouling sludge accumulation, or cold-weather gelling. However, best practices for biodiesel storage, and improved gaskets and seals that are biodiesel resistant, combined with regular maintenance and leak inspection schedule for the fuel lines and components enable the safe use of biodiesel in newer MD/HDVs.
- Propane (LPG, or autogas) presents well-known hazards due to overpressure in tank overfill, and unintended ignition (due to leaks or a crash) that are preventable by using Overfill Prevention Devices (OPD) that supplement the automatic stop-fill system on the fueling station side, and pressure release devices (PRD). Established best practices and safety codes (e.g. NFPA) have proven that propane fueled MD/HDVs can be as operationally safe as the conventionally-fueled counterparts.
- As the market penetration of hybrid and electric drivetrain accelerates, and the capacity and reliability of lithium ion batteries used in Rechargeable Energy Storage Systems improve, associated potential safety hazards (e.g., electrocution and stranded energy, thermal runaway leading to battery fire) have become well understood, preventable and manageable. Existing and emerging industry technical and safety voluntary standards, compliance with applicable NHTSA regulations and guidance, as well as growing

experience with the operation of hybrid and electric MD/HDVs will enable the large-scale adoption of safer and more efficient power-train electrification technologies.

Key safety findings from the literature review pertaining to the specific FE technologies implemented to date in the MD/HDV fleet include:

- Telematics, integrating on-board ITS sensors, video and audio alerts for MD/HDV drivers, offer potential improvements in both driver safety performance and fuel efficiency. Both camera and non-camera based telematics setups are currently integrated with available crash avoidance systems (such as ESC, RSC, LDWS, etc.) and appear to be well accepted by MD/HDV fleet drivers.
- Both experience abroad and the cited U.S. studies of trucks equipped with active speed limiters indicated a safety benefit, as measured by up to 50 percent reduced crash rates, in addition to fuel savings and other benefits, with good CMV driver acceptance. Any negative aspects were small and avoidable if all the speed limitation devices were set to the same speed, so there would be less need for overtaking at highway speeds.
- No literature reports of adverse safety impacts were found regarding implementation of on-board idle-reduction technologies in MD/HDVs (such as automatic start-stop, direct-fired heaters, and APUs).
- There was no clear consensus from the literature regarding the relative crash rates and highway safety impacts of LCVs, due to lack of sufficient data and controls and inconsistent study methodologies. Recent safety evaluations of LCVs and ongoing MAP-21 mandated studies will clarify and quantify this issue.
- Tire technologies for FE (including ATIS, TPMS, LRR and single-wide tires) literature raised potential safety concerns regarding lower stability or loss of control, e.g., when tires pressure is uneven or a single wide tire blows out on the highway. However, systems such as automated tire monitoring systems and stability enhancing electronic systems (ABS, ESC, RSC) promise to compensate and mitigate any adverse safety impacts.
- Aerodynamic technologies that offer significant fuel savings have raised potential concerns about vehicle damage or injury in case of detached fairings or skirts, although there were no documented incidents of this type in the literature. Conversely, there is a potential safety benefit from skirts that also function as side underride guards to protect VRUs in multimodal operating environments.
- The increasing use of light weighting materials may pose some safety and crashworthiness hazards, depending on their performance in structural or other vehicle subsystem applications (chassis, power-train, crash box or safety cage). Some composites (fiberglass, plastics, CFRC, foams) may become brittle on impact or due to weathering from UV and extreme cold, or consumed by fires. No examples of such lightweight material failures on MD/HDVs were identified in the literature. Industry has developed advanced, high performance lightweight material options tailored to their automotive application, e.g., thermoplastics resistant to UV and weathering.

Chapter 3 summarized the safety inputs offered by a representative group of SMEs regarding fleet adoption of FE technologies and alternative fuels. SMEs indicated that there was a learning curve to the process: design and engineer novel subsystems; integrate them safely in the vehicle; inspect, maintain and refuel fleet vehicles for safe operability; and train staff to safely operate a fleet of such new MD/HDVs. Although some SMEs raised specific safety concerns, their experience demonstrates that system- or fuel-specific hazards can be prevented or mitigated by observing applicable industry standards, and by training managers, operators and maintenance staff in safety best practices.

Specific safety insights mentioned by the SMEs, based on their experience included:

- Alternative fuels did not raise major safety concerns but generally required better education and training of maintenance staff and operators. There was anecdotal safety concern regarding high pressure (4,000 psi) CNG cylinders that could potentially explode in a crash scenario or if otherwise ruptured. However, aging CNG fuel tank safety can be assured by enforcing regulations such as FMVSS 304 and by periodic tank inspections, end-of-life disposal and replacement. A propane truck fleet manager found the fuel to be as safe as or safer than gasoline, and reported no safety issues with the company's propane, nor with hybrid gasoline-electric trucks.
- OEMs of drivetrain hybridization and electrification systems, including batteries for the rechargeable energy storage system indicated that they undergo multiple safety tests and are designed with fail-safes for various misuse and abuse scenarios. A potential safety risk was the integration of hybrid components downstream by bodybuilders in retrofits, as opposed to new vehicles. Another potential safety concern raised was the uncertain battery lifetime due to variability of climate, operation duty-cycles and aging degradation. Without state-of-charge indicators, vehicles could become underpowered or stranded if the battery degrades and is not serviced or replaced in a timely manner.
- ITS and telematics raised no safety concerns; on the contrary, fleet managers stated that "efficient drivers are safer drivers." Monitoring and recording of driver behavior, combined with coaching, appeared to reduce distracted and aggressive driving and provided significant FE and safety benefits.
- Tire technologies: Wide base tires safety concerns stemmed from the decrease in tire redundancy in case of a tire blowout at highway speeds. In the case of LRR, a concern was that these tires could negatively affect truck stopping distance and stability control.
- Speed-limiter safety concerns could be encountered when trucks pass other vehicles on the highway instead of staying in the right-hand lane behind other vehicles. However, by combining speed limiters with driver training programs the truck fleet safety performance could actually improve.
- Aerodynamic systems safety to date was satisfactory, with no instances of on-road detaching of components. However, covering the underside or other safety-critical components with aerodynamic fairings can make them harder to inspect, (e.g., worn lugs, CNG relief valve shrouds, wheel covers, and certain fairings). Drivers and inspectors need to be able to see through wheel covers and to be able to access lug nuts through them. These covers must also be durable to withstand frequent road abuse.
- For lightweighting materials, safety concerns raised were potentially lower crashworthiness (debonding, or brittle fracture in impact), and potential for decreased survivability in vehicle fires depending on the specific composite or other material choice and its application.

The scenario-based deterministic hazard analysis presented in Chapter 4 reflected not only literature safety findings and SME's safety concerns, but also reported truck or bus mishaps that have occurred. Key hazard analysis scenarios included: CNG-fueled truck and bus vehicle fire or explosion due to CNG tank rupture, when pressurized fuel tanks degraded due to aging or PRDs failed; LNG truck crashes leading to fires, or LNG refueling-related mishaps; the flammability or brittle fracture issues related to lightweighting materials in crashes; reduced safety performance for either LRR or wide-base tires; highway pile-ups when LCVs attempt to pass at highways speeds; aerodynamic components detaching while the vehicle traveled on a busy highway or urban roadway; and fires resulting to overheated lithium ion batteries in electric or hybrid buses. All these hypothetical worst case scenarios were shown to be preventable and possible to mitigate by observing safety regulations and voluntary standards, or with engineering and operational best practices.

7 APPENDICES

7.1 Operations/Human Factors Bibliography

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