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TRAILER TECHNOLOGIES FOR INCREASED HEAVY-DUTY VEHICLE EFFICIENCY

TECHNICAL, MARKET, AND POLICY CONSIDERATIONS

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EXECUTIVE SUMMARY

In the United States, and many countries around the world, on-road freight is the fastest-growing source of transportation-related fuel consumption and greenhouse gas (GHG) emissions. Heavy-duty tractor-trailers represent a sizable portion of the goods moved in the United States and also account for a significant percentage—approximately 60 percent—of the total fuel used by on-road heavy-duty vehicles. Since economic growth has historically been tied to increases in freight activity, improving the efficiency of tractor-trailers is a critical task worldwide in order to reduce the air pollution and climate impacts of the transportation sector.

There are a number of different strategies for reducing fuel use and CO_2 emissions from tractor-trailers, but this paper centers on ways to increase per vehicle fuel efficiency—specifically, technologies for increasing trailer efficiency. In general, the efficiency of a trailer can be improved by reducing the aerodynamic drag, the rolling resistance, or the weight of the trailer.

For trailer aerodynamics, there are many technologies that exist and are in development to target each of the three primary areas where drag occurs: 1) the tractor-trailer gap, 2) the side and underbody of the trailer, and 3) the rear end of the trailer. Individually, technology innovations devised for each of these three areas typically provide overall fuel savings of between 2 and 7 percent for driving at highway speeds. In addition to aerodynamic improvements, lowering the rolling resistance of tires through enhanced design and proper inflation can also reduce the power required to move the tractor-trailer down the road. Tire technologies continue to progress, and there are many trailer tire models (for standard-sized tires as well as wide-base single tires) that offer low rolling resistance and thus contribute directly to fuel savings. Looking at the specific contribution of trailer tires to overall tractor-trailer rolling resistance drag, improvements can yield fuel savings on the order of 1 to 5 percent for typical long-haul operations. Savings at the high end of this range represent the benefits of wide-base single tires, which, in addition to their lowered rolling resistance, offer the reduced weight associated with having half as many wheels and tires. Finally, alternative materials such as composites and aluminum can be used in trailer wheels as well as the structural supports in order to decrease the empty weight of the trailer, which leads to reduced rolling resistance and inertial drag.

Despite a host of trailer aerodynamic and tire options that have been shown to provide real-world fuel savings that generally pay back the initial capital investment within one to two years, there are many economic and technical barriers that have slowed their adoption to date. Perhaps at the forefront of these barriers is end users' uncertainty about the potential fuel savings that a given technology can provide for their particular mission. Third-party, unbiased assessment of technology efficacy may be difficult to obtain, and it can often be an expensive proposition for fleets to conduct their own testing or pilot programs. Programs such as the U.S. Environmental Protection Agency's (EPA) SmartWay Transport Partnership are working to combat this uncertainty by testing and validating technologies and providing a repository where industry can find data and information about technology performance. Other impediments to wider adoption include financial constraints such as capital availability, short payback time requirements, or warranty issues as well as the potential inconvenience that a technology might present in terms of disrupting operations or demanding additional maintenance. In addition, size and weight restrictions can present regulatory barriers.

As with the commercial vehicle sector, the trailer market is diverse, and there are a variety of sizes and configurations that are employed to meet a wide range of freight demands. Despite this great diversity, box-type vans represent more than two-thirds of the sales market and likely constitute a large percentage of total trailer miles traveled. In terms of manufacturing and sales, the trailer market is fairly consolidated, with the largest five companies accounting for nearly two-thirds of total sales. The van trailer marker is even more consolidated, with the top five companies making up more than 90 percent of total sales.

In the United States there have been two primary programs targeting trailer efficiency improvements. The first is the EPA's voluntary SmartWay Transport Partnership, which, since its inception in 2004, has spearheaded a number of initiatives focused on verifying trailer technology performance and disseminating information and test data free of charge to fleet users and the general public. Building on the success of the SmartWay program, the California Air Resources Board crafted a mandatory regulation for both tractors and trailers operating in California that went into effect in 2010. For trailers, the California Heavy-Duty Greenhouse Gas rule includes provisions for both aerodynamic and rolling resistance improvements that will be phased in over the course of the decade (to 2020).

In the recently finalized regulation for medium- and heavy-duty vehicles, the EPA and the National Highway Traffic Safety Administration acknowledged that there are substantial fuel savings to be achieved by focusing on trailers. However, the agencies said that they would not include trailers in the Phase 1 vehicle regulation primarily due to time constraints and the need to reach out to the trailer industry, which has never been held accountable in terms of fuel efficiency or GHG emissions. As policymakers in the United States and across North America weigh options for trailer policy measures, the following are the ICCT's recommended actions:

1. **Integrate trailers into the Phase 2 U.S. heavy-duty vehicle regulatory program.** The inclusion of trailers will increase the fuel and GHG reductions from the program, resulting in additional fuel savings for end users.
2. **Create an opportunity for early deployment of trailer technology.** This will allow ample time for the trailer industry to familiarize itself with the various aspects of the rule, including testing, compliance, flexibility mechanisms, and reporting.
3. **Focus the regulatory requirements on box-type trailers but incentivize improvements for non–box trailers as well.** Regulating box trailers will yield the majority of benefits from a trailer program; however, tire rolling resistance standards can be introduced for all trailer types, and aerodynamic and weight reduction improvements in specialty trailers can be spurred through a scheme that offers credits to incentivize their use.
4. **Use an identical test method and certification approach for tractors and trailers.** Tractor-trailers operate as a system and, as such, should be subject to the same test procedures for determining aerodynamic performance.

1 INTRODUCTION

Worldwide, freight vehicles are a major and growing contributor to fuel consumption and climate change emissions in the on-road transportation sector. In the 2020 to 2030 time frame, heavy-duty vehicle emissions will become approximately equivalent to those of automobiles, currently the largest overall contributor to climate change within the transport sector (see Figure 1-1) (Facanha, Blumberg, and Miller 2012). In many regions around the world, the majority of goods that are transported by road are borne by heavy-duty combination tractor-trailers. As a result, tractor-trailers often account for the largest percentage of vehicle-miles traveled and thus fuel consumption and emissions from heavy-duty vehicles. For example, in the United States, tractor-trailers are estimated to represent roughly 60 percent of the total fuel use and greenhouse gas (GHG) emissions from the on-road heavy-duty sector, which also encompasses construction vehicles, refuse haulers, buses, and other trucks including large pickups (U.S. Environmental Protection Agency 2011a).

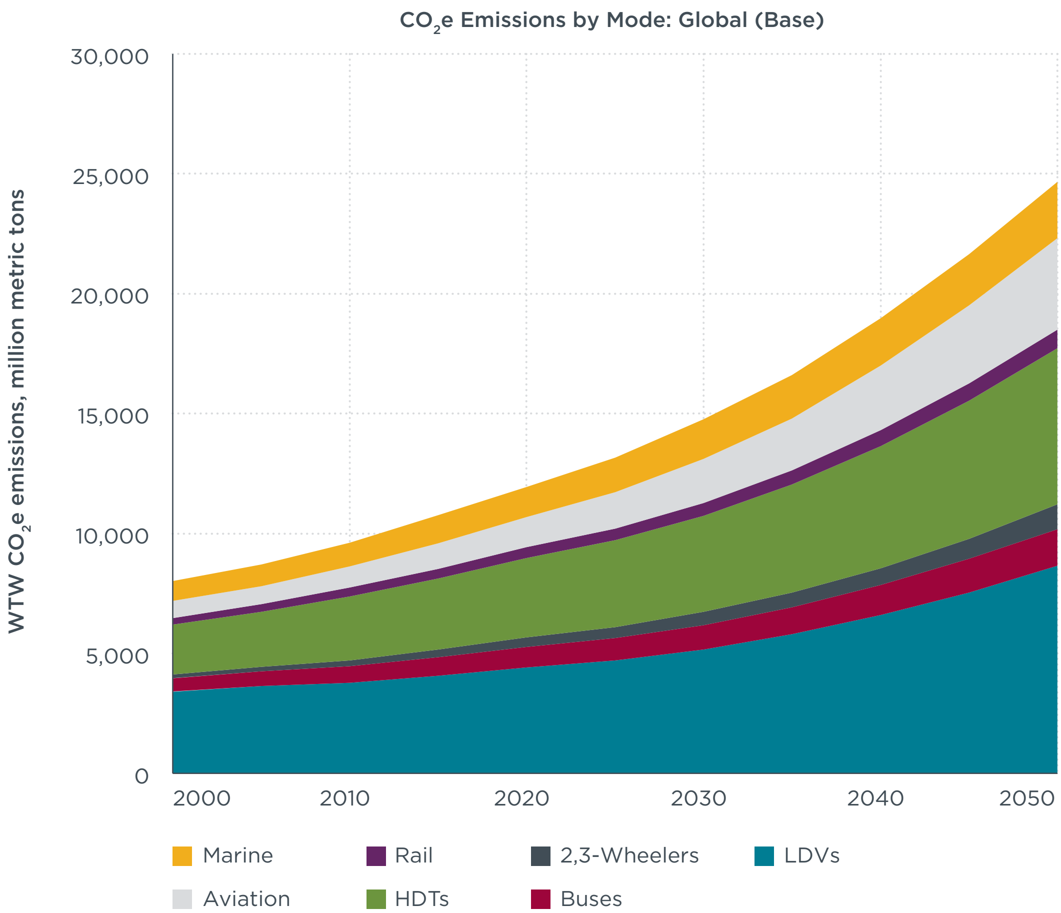

Figure 1-1: Global on-road transportation

Achieving dramatic reductions in overall heavy-duty vehicle energy use and GHG emissions, especially in light of widespread projections of increasing freight activity, has proved to be difficult in practice. Economic development has historically been linked to increased freight activity, so as populations and economies worldwide continue to expand, a key challenge in the coming decades will be curbing emissions and fuel use from the most energy-intensive of heavy-duty vehicles—combination tractor-trailers.

Categorically, the findings from literature indicate that there is a large portfolio of extant and emerging technologies for all the major heavy-duty vehicle segments. Vehicle makers and suppliers have been aggressively developing and beginning early deployment of these technologies. Specifically, there are a variety of engine, transmission, and overall vehicle technologies for tractor-trailers that can significantly and cost-effectively reduce fuel consumption.

In recent years, many governments around the world have begun to take targeted steps to promote these fuel-saving technologies within their heavy-duty vehicle fleets. The earliest such regulatory effort, in Japan, was promulgated in 2006 and requires engine efficiency improvements for new vehicles by 2015. The U.S. heavy-duty vehicle program was finalized in 2011; it specifies different GHG and efficiency standards for tractor-trailers, vocational vehicles, smaller pickups, and vans, as well as separate engine standards. California has been especially active in promoting heavy-duty vehicle efficiency by designing regulations aimed at end users. In 2012, China published standards for model-year 2015 vehicles that include full-vehicle testing to ensure the entire vehicle is encompassed in the regulatory program. In early 2013, Canada published standards for heavy-duty vehicles that are fully harmonized with the U.S. program in all significant aspects of regulatory design. In addition, Mexico and the governments of the European Union are actively developing policy measures to accelerate the adoption of fuel-saving technologies for commercial vehicle fleets.

Within the U.S. heavy-duty vehicle GHG program, a range of technologies will be deployed to comply with the Phase 1 performance-based standards that affect model-year (MY) 2014 to 2018 vehicles. Prominent among the technologies will be refinements to fuel injection systems (e.g., the fuel rail and injectors), turbocharger efficiency, engine improvements (the cylinder head, pistons, friction reduction), and auxiliary system adjustments (water, oil, and the fuel pump). In addition, the program will promote full-tractor-body advances such as aerodynamic improvements from roof deflectors, fairings, and bumpers; low rolling resistance tires; mass reduction through the use of lightweight materials; and idling control technologies.

Critically, the initial U.S. heavy-duty vehicle scheme delayed the incorporation of trailers within the rulemaking owing to a number of constraints at the time. As a result, the program does not acknowledge and credit trailer improvements already available that would reduce GHG emissions and fuel consumption, nor does it further the development and deployment of new trailer technologies.

The omission of trailers from the first phase of the U.S. heavy-duty vehicle regulation prompted this report's investigation of the potential of trailer technologies to increase tractor-trailer efficiency. In their analysis of regulatory alternatives for Phase 1, the U.S. Environmental Protection Agency and the National Highway Traffic Safety Administration considered an option in which dry and refrigerated van trailers would be subject to standards. In that alternative, the average fuel consumption of a MY 2017 tractor-trailer was estimated to be roughly 17 percent lower than the baseline MY 2010 vehicle. In the vehicle program as actually instituted, not taking into consideration trailer improvements, the average fuel consumption of a MY 2017 tractor-trailer was estimated to be about 13 percent lower than the MY 2010 baseline.

This report is narrowly focused on updating the discussion of the technical, market, and policy dimensions of trailers themselves and the prospects for improving tractor-trailer efficiency through regulation. Although it concentrates on the regulatory context of the United States, the implications of the work are broader. The governments of Canada, Mexico, the European Union, Japan, China, and other nations grapple with similar policy questions and similar demands to increase tractor-trailer efficiency.

The report seeks to inform policymakers on the question about how best to support trailer technologies that can offer cost-effective GHG emission and fuel consumption reductions. These are its primary objectives: (1) Cataloging the technologies and approaches for reducing aerodynamic drag and rolling resistance in trailers; (2) Providing an overview of the dynamics of the U.S. trailer market as relating to technology adoption and potential policy implications; and (3) Examining policy options for accelerating the deployment of cost-effective trailer technologies. As such, the remainder of the report is organized into five chapters:

» Chapter 2 describes the aerodynamic and surface resistance that act upon tractor-trailers and puts forward technologies for reducing each of these drag forces.
» Chapter 3 presents an analysis of the new trailer sales market, with a focus on the years 2008 to 2011.
» Chapter 4 summarizes the existing policies that target trailer fuel efficiency.
» Chapter 5 outlines policy options for the trailer sector in the United States and, more broadly, North America.
» Chapter 6 summarizes the assessment's findings and offers recommendations for policymakers.

2 TECHNICAL BASIS FOR TRAILER-BASED EFFICIENCY IMPROVEMENTS

Fundamental physics dictates that the aerodynamic drag, the rolling resistance between tires and the road, and the inertial acceleration needed because of the weight of a trailer all present forces that must be overcome to propel a heavy-duty tractor-trailer. This chapter investigates the fundamental characteristics of the aerodynamics of trailers, tire rolling resistance, and opportunities for mass reduction and describes the technologies that are available in each of these areas for diminishing drag and increasing efficiency.

2.1 ENERGY BALANCE OF A TRACTOR-TRAILER

Looking at the overall energy picture of a tractor-trailer operating at a constant 65 miles per hour with no grade (see Figure 2-1, whose values come from the U.S. Department of Energy 21st Century Truck Partnership Roadmap) (U.S. Department of Energy [21st Century Truck Partnership] 2006)), energy losses in the engine, amounting to 240 kilowatt hours (kWh), account for roughly 60 percent of the total energy used during an hour of constant-speed highway driving. The energy to move the tractor-trailer includes energy losses associated with aerodynamic and rolling resistance, the drivetrain, and auxiliary loads, which collectively represent the remaining 40 percent of the total energy expended. Focusing on nonengine losses, aerodynamic drag and rolling resistance account for approximately 85 percent (i.e., [85 kWh + 51 kWh] / [85 kWh + 51 kWh + 15 kWh + 9 kWh]) of the energy required to move the vehicle. Auxiliary loads (e.g., ventilation and climate control, lighting, compressor, fans) and losses in the drivetrain make up the remaining 15 percent. Rolling resistance and aerodynamic drag are usually similar in magnitude at freeway speeds. At constant highway speeds (roughly 60–65 mph), a percentage point reduction in aerodynamic drag (C_d) and rolling resistance (C_{RR}) yields roughly a half percent and a one-third percent reduction, respectively, in overall fuel consumption. Using the energy balance assumptions of the U.S. Department of Energy (21st Century Truck Partnership) (2006) for a tractor-trailer driving at 65 mph, a 10 percent decrease in aerodynamic drag would result in roughly a 5 percent reduction in overall fuel consumption, assuming that engine efficiency is unaffected by load. For rolling resistance, a 10 percent reduction would result in a 3 percent decline in fuel use.

In examining the energy expenditures (adapted from Table 3.1 in U.S. Department of Energy [21st Century Truck Partnership] [2006]), it is important to note that the payload carried in the trailer has important ramifications for the loss percentages, particularly for aerodynamics and rolling resistance. As payload decreases, the force on the tires—and thus the rolling resistance—is reduced. As a result, aerodynamics make up a greater percentage of the losses compared with rolling resistance in cases where tractor-trailer is operating at less than the maximum gross vehicle weight rating (GVWR) of 80,000 lbs. According to an MJ Bradley & Associates analysis (Lowell and Balon 2009), only 30 percent of tractor-trailer miles traveled take place with weights of 80,000 lbs. or more, while the remainder of such trips are either volume restricted (i.e., “cube-out,” for payloads that are intrinsically light, maximum volume is reached before maximum weight) or carry less than full loads.

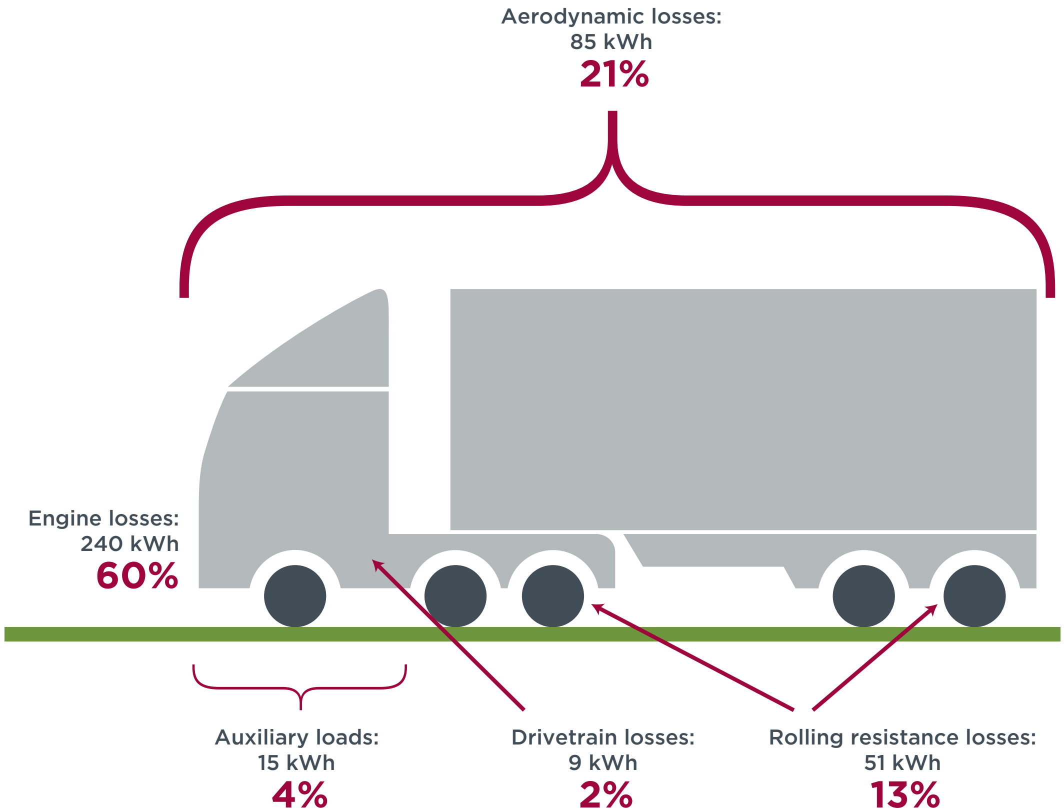

Figure 2-1: Energy audit of a fully loaded (80,000 lbs. GVWR) tractor-trailer traveling at 65 mph for one hour

Based on data from U.S. Department of Energy (21st Century Truck Partnership), 2006

A North American tractor with a dry-van[10] or refrigerated trailer has a frontal area of about 100 square feet. At 65 mph, the tractor-trailer's frontal area displaces around 40,000 lbs. of air every minute. That figure approaches the standing empty weight of the tractor-trailer itself. This air must be accelerated to make way for the tractor-trailer. It then passes across the top and the sides of the vehicle, with the disrupted air streams merging again in the vehicle's wake. Aerodynamic improvement allows more of the energy required to displace the air to be recovered as the air decelerates in its wake.

Consider a cube, as a very simple representation of this truck, moving through air, with the leading face perpendicular to its axis of motion. The cube displaces air in front of itself, and the air streams flow down the top and sides of the cube and merge again behind the cube. As shown in Figure 2-2, there are two separate contributions to drag force on the cube. First, the pressure in front of the cube is higher than the pressure behind it, leading to a net retarding force (sometimes called a suction force) in the axial direction. Second, there are shear forces on the four sides (including top and bottom) that are parallel to the flow. These shear forces are associated with a velocity gradient that arises because the air at the surface of the cube has the same velocity as the cube, whereas the air far from the moving cube is either still or moving at the prevailing wind speed.

10 Throughout the paper, the terms box and van are used interchangeably as descriptors for trailers that have rectangular cuboid dimensions.

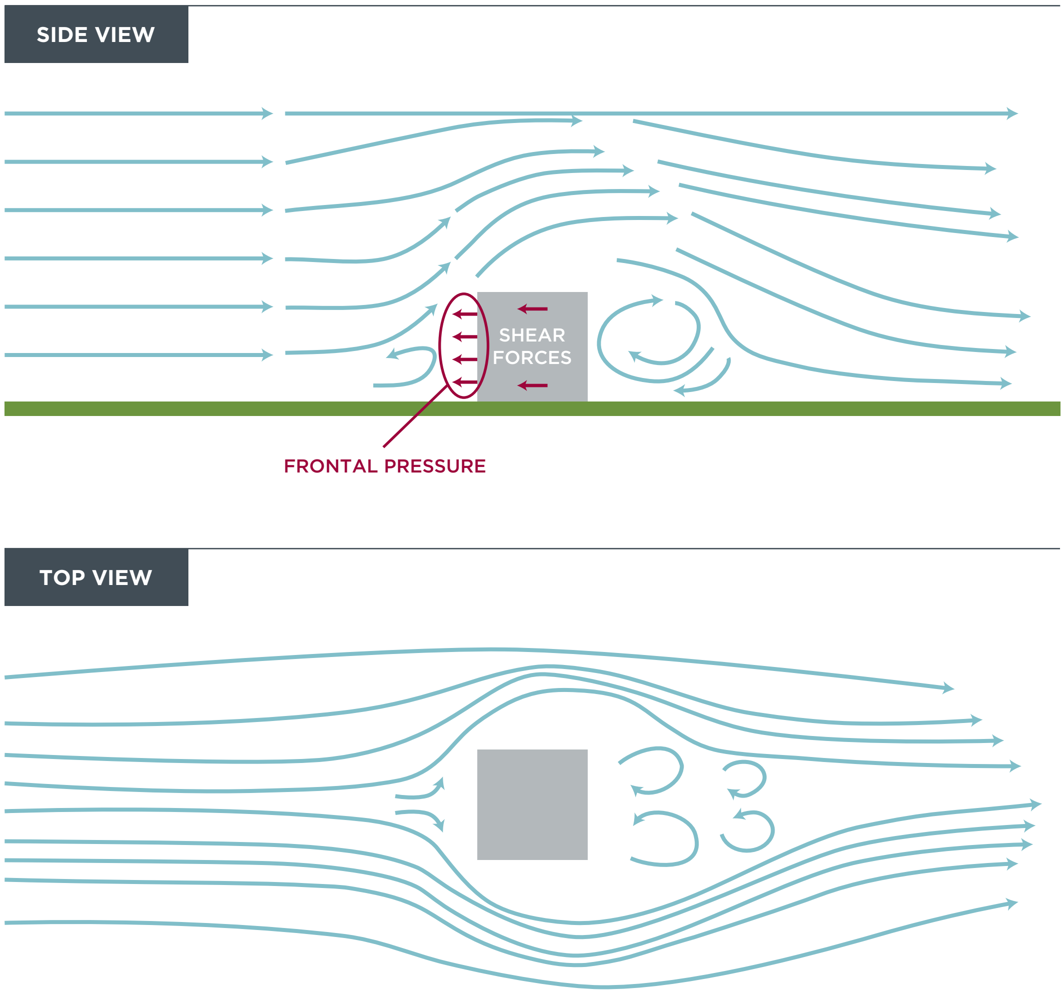

Figure 2-2: Side and top view of air flow around a cube

When air is accelerated to the traveling velocity, to move out of the way of the cube, some of the air's static pressure is translated into dynamic pressure. The static pressure can be restored only if the air decelerates again without developing eddies. The deceleration in the cube wake does not raise the static pressure appreciably, so the pressure on the back of the cube is lower than the pressure at the front, representing net frontal drag.

The net pressure force on the cube is customarily described as being proportional to the square of the velocity, although it in fact varies in a more complex fashion with respect to velocity. The shear forces (skin friction) in simple theory vary in direct proportion to velocity, but this relationship is also approximate. It is cumbersome to describe the total force on the cube in terms of these two different effects, and thus they are usually lumped into an equation that mimics the pressure force. The drag force, *F*, on the cube, is therefore usually expressed as

$$F = 0.5\ C_d\ A\ V^2$$

where A is the frontal area of the cube, around which the air must flow, V is the velocity of the cube through the air, and C_d is a drag coefficient, which is empirically defined by this equation. The drag coefficient is not constant over a range of velocities because the actual flow is more complex than can be described by the simple equation. For this reason, it is always important to present the applicable frontal area and velocity when introducing a drag coefficient into a data set.

Now consider a box that is the size of two cubes placed one behind the other and touching. The frontal area A remains the same, but the side area doubles. This example is depicted in part A of Figure 2-3, where Cube 1 and 2 have identical dimensions. The value of the drag coefficient rises for the two-cube case. However, neither the force nor C_d doubles. The skin friction on the lead cube is higher than that on the following cube, and the pressure differential between front and back is not experienced twice. By similar example, a railroad train with 100 cars will have a higher drag coefficient than one with 50 cars, but it will not be twice as high.

However, if the two cubes move through air as one unit but are separated by a gap, C_d is greater than in the case where they are touching because the gap between them will disrupt the air flowing around the cube faces, or boundary layer, and this boundary layer will need to be re-established for the second cube. C_d increases with gap size. This case is shown in part B of Figure 2-3. These two cubes, separated by a gap, are symbolic of a road tractor and van trailer, and they illustrate the efficiency advantage of reducing the gap between tractor and trailer and keeping the flow in smooth transition from the trailing edge of the tractor to the leading edge of the trailer.

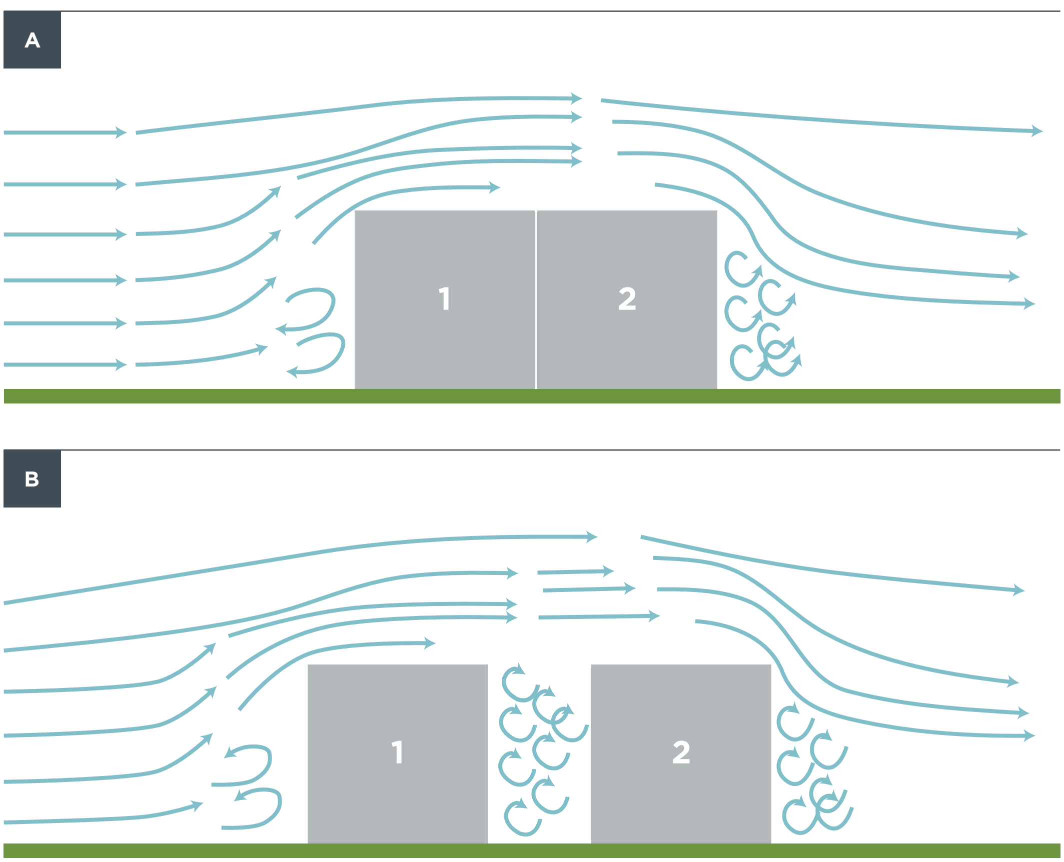

Figure 2-3: Air flow around two cubes and the effect of a gap between the two bodies

The two-cube arrangement also yields higher drag when the lead cube (i.e., the tractor) is smaller than the trailing cube (the trailer), even if they are arranged on the same center axis. This situation is illustrated in part A of Figure 2-4. To reduce the overall drag on this pair of cubes, a ramp, rather than a bluff front, is needed to deflect the air from the side surface of the smaller cube to the side surface of the larger cube as shown in part B of the figure. This conclusion has led to the adoption of sloping rooftop surfaces and gap fairings on tractors, as discussed below.

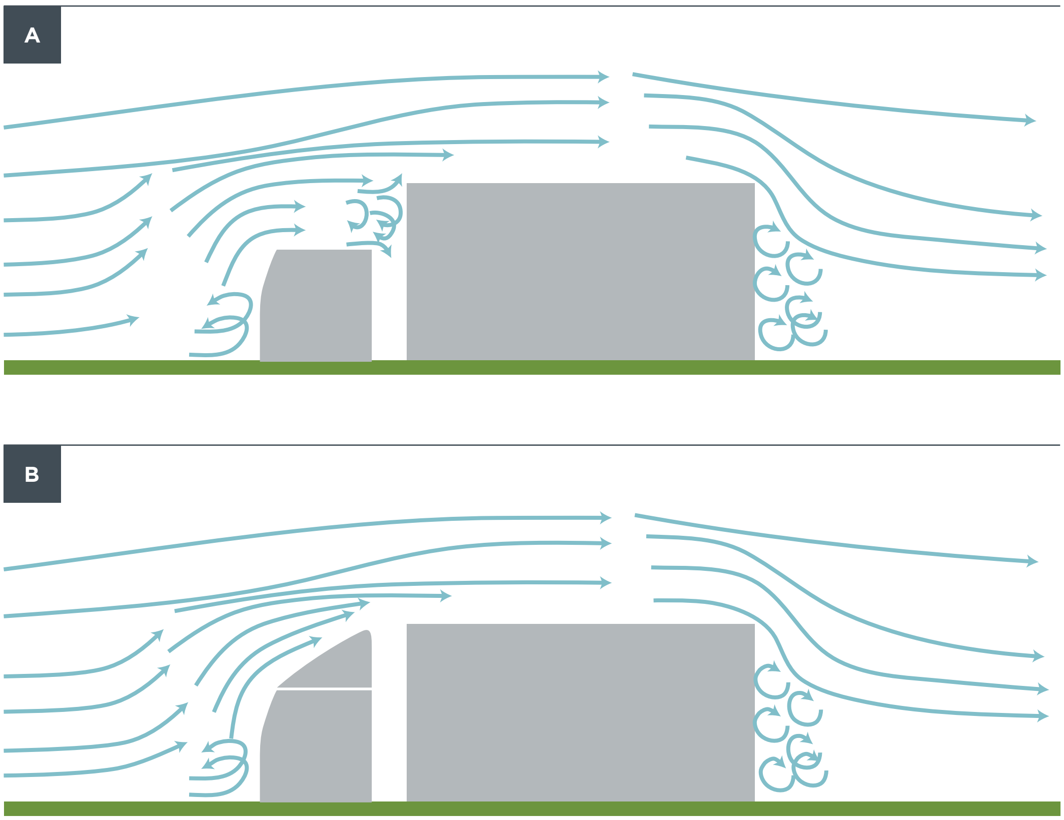

Figure 2-4: Conceptual diagram of the effect of a roof deflector fairing

If the cube is moving through air a set distance above a stationary surface (as with the underside of a truck above a roadway), some of the air encountered by the cube is accelerated and directed between the cube and the surface. Between these two, the air creates a velocity gradient, which causes a drag force between the cube and the surface. The air flow still involves boundary layers, but itis affected by the distance between the cube and the stationary surface and develops differently from the layers on the other three parallel sides. Trucks are equipped with air dams (or low bumpers) to reduce the direction of air into the gap between the truck body and the road. As shown in part B of Figure 2-5, where the front bumper deflects air away from the space between the tractor-trailer and road surface, the less air that is sucked into this zone, the less air must be accelerated.

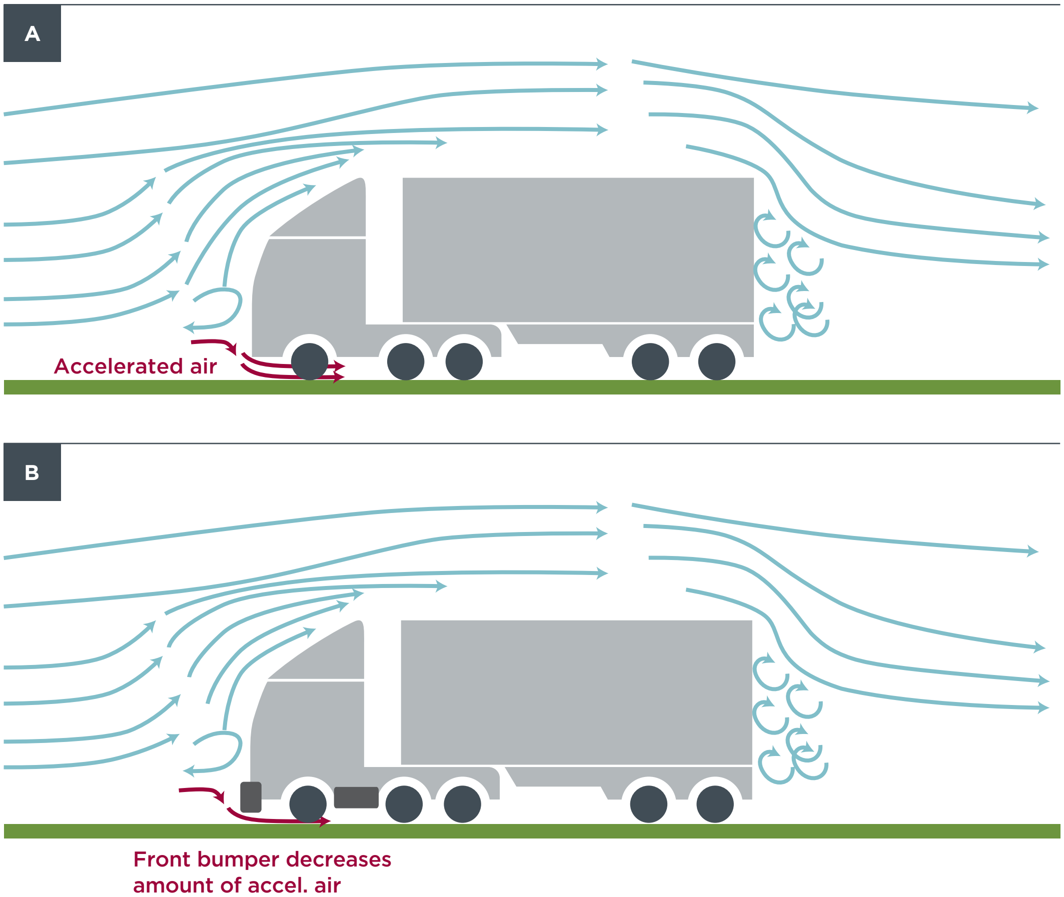

Figure 2-5: Front bumper reduces air flow between the tractor-trailer and the road surface

Other basic flow concepts are at play. It is well documented that the roughness of a surface can affect the boundary layer and hence the drag force. The boundary layer is thick over most of the length of a trailer, but protrusions such as vertical ribs will disrupt it, leading to more drag.

Aerodynamic drag can also be viewed from an energy perspective rather than through the inertia and force concepts presented above. The truck imparts kinetic energy to the air by accelerating the air to range of velocity values. This results in velocity gradients, which ultimately, due to viscosity of the air, translate into a loss of kinetic energy to heat. Eddies that form in the gap between the tractor and trailer, under the trailer, and in the wake, all decay and serve to create heat from kinetic energy through viscous dissipation.

A historical flow concept that can be used to envision energy expenditure and resistance is mixing length theory. If one takes a "packet" of still air and moves it into the vicinity of any truck surface, the truck has to accelerate that packet, which requires force (or energy) from the truck. When that packet moves away into the bulk of the air, it does not return that force to the truck or resupply the truck with kinetic energy. By this argument, any movement of air to and from the truck surface represents added drag. This packet movement occurs when eddies of air are present near the truck. The mixing length concept also explains how crosswinds intensify resistance by bringing fresh packets of air near or under the truck. Since those packets have no forward velocity, they must be accelerated by the truck and trailer, leading to higher losses of energy. Simply put, the more that the air near the truck is stirred, mixed, and exchanged, the greater will be the drag.

2.2 INFLUENCE OF WIND

When there is a prevailing headwind or tailwind, the relative velocity between the truck and the air will change. Regrettably, tailwinds and headwinds do not cancel out one another exactly over the operating life of a truck because the drag force is roughly proportional to the square of the relative speed. Thanks to the squared term in the equation, the intensification of drag from a headwind exceeds the lessening of drag from a tailwind of the same velocity.

Crosswinds, winds that buffet the truck from directions other than straight on or squarely behind, produce a yaw angle, which is the angle at which the relative velocities of the truck and the air are at a maximum differential. In Figure 2-6, the wind acts at an angle with respect to the longitudinal axis of the vehicle. The angular wind vector can be resolved into longitudinal (x-axis) and perpendicular (y-axis) components as shown in the figure. Crosswinds may have different effects on different parts of the trailer. They will deliver a net force to one side of the tractor and trailer. This will result in variable stresses on the tires, causing them to slip in a distinct way, and the need to correct the truck direction by setting a steering angle. The resulting additional tire rolling resistance may be seen as an aerodynamic loss. In addition, high-frequency gusts will disrupt the truck's or trailer's boundary layer, increasing the drag.

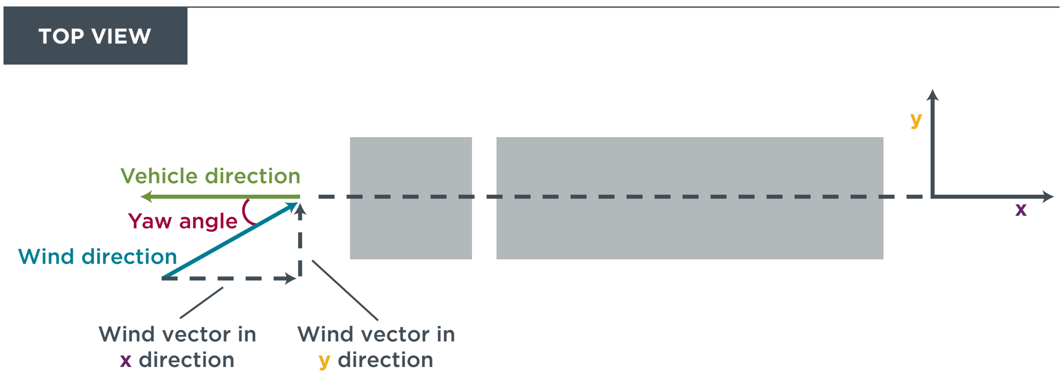

Figure 2-6: Yaw angle

2.3 TRAILER-TRACTOR INTERACTION

This discussion examines aerodynamic drag on trailers, but the trailer cannot be isolated from the truck in any analysis. It is important to define trailer drag in some consistent fashion: consider that the trailer drag is the sum of the axial forces at the tractor fifth wheel and at the rear suspension. First, the truck dictates the upstream conditions and sets the airflow field that encounters the trailer. Trucks with substantially distinct aerodynamic designs or with varying gap separation from the trailer will affect the drag on the trailer differently while operating at steady speed. They may also affect the benefit conferred by trailer aerodynamic devices. Second, it is important to note that some drag reduction devices, such as truck rooftop fairings, could, in theory, equally well be attached to the trailer. However, trucks have received greater attention because they are outnumbered substantially by trailers, because geometric constraints favor attachment of devices to the truck, and because some aerodynamic devices offer inside headroom in sleeper cabs. Third, it is not clear whether the truck or the trailer is responsible for the losses associated with the gap, but the consistent definition of trailer drag presented earlier in this paragraph can render this consideration redundant. The presence of the trailer, even when the drawbar pull is subtracted, will affect the truck's own drag force.

2.4 AVAILABLE DESIGNS AND DEVICES

2.4.1 Sides and underbody of the trailer

In contrast to road tractors, which offer subtle design opportunities for aerodynamic drag reduction, trailer options have been few and simple. The most common devices added to trailers are skirts, which extend below the trailer on each side between the rear of the tractor and the trailer axles. These may be parallel to the trailer axis, or angled outward to the rear, and they serve to limit flow of air between the underside of the trailer and the roadway on either side of the trailer. This reduces the transfer of momentum from the truck to the surrounding air and presumably also helps to reduce the delivery of air to the underside of a trailer by a crosswind. Present-day devices usually consist of a flat composite or metal sheet, often with a flexible lower section to avoid road impact (break-over) or railroad crossing damage. Designs with a vertical or lateral bend also exist. The science of measuring or modeling trailer drag is sufficiently precise to allow the demonstration of the effectiveness of skirts but probably not the relative effectiveness of designs with subtle differences. Most of these devices are retrofit components, which do not fully seal the underside of the trailer and do not necessarily work in close conjunction with minimizing losses at the rear axles. Designs exist, particularly in Europe, where the side skirting is integrated and where the rear tires are housed within fenders, but these trailers differ fundamentally from the designs used in the U.S. market.

An underbody surface is a separate device that consists of a surface angled downward under the body of the trailer, directing the air beneath the axle tubes.

Wheel covers may be used on trailer wheel rims as well as on tractor rims. The addition offers modest improvements but is inexpensive. The air pocket in the rim is contained, reducing eddies that lead to losses.

2.4.2 Tractor-trailer gap

A trailer gap fairing is a rounded protrusion (or bent panel) at the leading edge of the top of the trailer, which may serve to offset losses associated with a truck with an aerodynamic contour that is not the full height of the trailer. It may also add to the benefit of a truck with a full-height aerodynamic profile by reducing the gap effect.

Various systems, some resembling accordion-like structures, have been devised and patented to close the gap fully while allowing angular change between the tractor and trailer. A curved gap has been proposed to reduce drag in the presence of crosswinds. These devices are not commercially available at this time.

2.4.3 Rear of the trailer

Various devices exist to decelerate the air passing over the roof and sides of the trailer and to reduce losses in the wake. They serve to diminish the trailer's cross section over a short distance but add to the overall trailer length. One of the simplest designs—trailer end fairing, tail fairing, or boat tail—offers two panels, positioned in a similar fashion to trailer doors that are three-quarters open, extending about three feet behind the trailer. The intent is to preserve the boundary layer attached to these fairings and to restore pressure by slowing the air to the rear of the trailer sides. An inflatable version exists, in which three panels resemble air mattresses. Additional panels for the roof or floor may be included, leading to a rectangular funnel shape when all four panels are deployed. Several total rear enclosure designs exist, all being “bubbles” or distorted hemispheres. All seek to reduce the tail diameter over three or four feet to the aft of the trailer doors. Where these devices are solid, there is a need to remove them or somehow collapse them for access to the rear doors. Some hemispherical designs are deployed by inflating air.

2.5 ROLLING RESISTANCE AND TIRE TECHNOLOGIES

When a tire rolls on the road, it deforms in shape to accommodate a moving “contact patch.” The tire, composed of belts and elastomers, is not a fully elastic structure, and the deformation causes energy loss. The energy required to rotate the tire on the road causes tire heating. Generally, the higher the tire inflation, the smaller is the contact patch: deformation and energy loss are then reduced, but the need for traction and reasonable pavement pressure dictates a limit to inflation. The energy that is delivered to the tire can be interpreted as a force in the direction of vehicle motion, multiplied by the distance that the vehicle travels. Although the force exerted is a complex function of both vehicle load and speed, the force required to roll the tire is often approximated as proportional the load (weight) that the tire carries. The constant of proportionality is termed the coefficient of rolling resistance (C_{RR}) and is defined as follows:

$$C_{RR} = \text{resistive axial force / normal force}$$

Values for C_{RR} are dimensionless and are typically less than 1 percent (0.01), but virtually all current production tires for modern heavy-duty vehicles have a C_{RR} well below this value, typically between 0.004 and 0.008 (Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles 2010).

Procedures to measure C_{RR} are becoming standardized, but they may not reflect the actual in-use values owing to the slight speed and load dependence of the parameter and the dependence of C_{RR} on the type of road surface and tire pressure. During a truck coast-down procedure, the deceleration at low speeds is dominated by tire rolling resistance, but brake drag and losses resulting from bearings, the driveshaft, and the rear of the transmission imply that the coefficient obtained from coast-down overestimates C_{RR}. Values of C_{RR} change when tires are steering and cornering, or when they experience a side thrust while rolling. A truck driving in a crosswind is likely to incur greater rolling resistance because of steering angle and side thrust, and this contributes additional aerodynamic losses to the energy accounting. Also, when the tires are delivering propulsion torque, they complete more revolutions per unit distance of vehicle travel, and when they are delivering braking torque, they complete fewer revolutions. This “longitudinal slip” is expressed as apparent change in C_{RR}. Although basic theory can contend with many of these subtleties, comprehensive data are not available, and most models for C_{RR} are thus deficient in that they are overly simplified.

The energy losses occur both in the tread area and the tire sidewalls. Both the tread area and the sidewalls can be designed to absorb less energy, thereby reducing C_{RR}. This may include the choice of elastomers, arrangement of belts and reinforcement, or tread design. As a result, there are “low rolling resistance” tires in the marketplace. Since some advantage may come from the tread design, the advantage of the low rolling resistance tire relative to a conventional tire may shrink as the tread wears (Goodyear Tire & Rubber Company n.d.). One of the potential downsides that must be balanced in tire design is the reduced traction and braking performance that is associated with lowering rolling resistance.

Further reductions in tire rolling resistance may be obtained by using wide-base single (WBS) tires. A WBS tire can carry a high load and can be substituted for a dual tire set: there are only two sidewalls to flex rather than four, and the energy associated with deformation is reduced. In addition, the rotational inertia is reduced by use of a wide-base tire (and only one rim), leading to reduced energy loss to friction braking in highly transient (i.e., stop-and-start) driving conditions. WBS tires may be unsuited to operations involving a great deal of tight cornering because of scrubbing by the wide contact patch and the imposition of different velocities on the widely spaced sidewalls. Standard dual tires can accommodate cornering more readily by having opposing longitudinal slip on the two separate tires.

Beyond improved tire designs, automatic tire inflation and air pressure monitoring systems can also lower the rolling resistance by helping drivers maintain their tires at optimum pressure. Rolling resistance is strongly related to the air pressure in the tire, increasingly steadily as tire pressure declines below the manufacturer's recommendation. According to Goodyear, the approximate relationship is that every 10 pounds per square inch (psi) underinflation results in 1 percent poorer fuel economy (Goodyear Tire & Rubber Company, n.d.).

The U.S. Environmental Protection Agency's SmartWay program presents a list of accepted low rolling resistance (LRR) tires and retread technologies for Class 8 long-haul tractor-trailers on its website. It is difficult to set up a baseline for conventional tires because their values for C_{RR} vary widely and because values for C_{RR} have been reduced over time. However, based on its testing program, the EPA established the values show in Table 2-1 (U.S. Environmental Protection Agency 2011) as the threshold for designation as an LRR tire for trailers. The EPA site states that fuel savings of 3 percent or more are possible by adopting LRR tires or retreads, which would reasonably correspond to a 10 percent reduction in C_{RR} for long-haul operation.

Table 2-1: Target values for SmartWay-certified low rolling resistance trailer tires

Test Procedure	C_{RR}
J1269 Application Test Point (1.7-meter drum)	0.0055
J1269 Test Point 2 (1.7-meter drum)	0.0055
J1269 5 point average (1.7-meter drum)	0.0056
ISO 28580 (2-meter drum)	0.0051

Source: U.S. Environmental Protection Agency, 2011b

Rolling resistance forces are greater than aerodynamic forces at lower speeds, and the opposite is true at higher speeds. In describing how the forces acting on a tractor-trailer are a function of vehicle speed, Tanguay (2012) presents an example for a typical tractor-trailer in which the rolling resistance forces dominate until roughly 90 kilometers/hour (~ 55 mph); at higher speeds, aerodynamic drag is the largest force. Therefore, LRR tires offer the greatest fuel savings (as a percentage) at low and medium speeds.

2.6 MASS REDUCTION TECHNOLOGIES

From a fundamental physics perspective, decreasing the weight of a vehicle reduces the forces needed to accelerate or decelerate the vehicle as well as the forces needed to overcome rolling resistance, which, as described the section above, are approximately proportional the load on the tires. In both tractors and trailers, manufacturers have commercialized and continue to develop products that utilize alternative materials such as aluminum and composites that lower the curb weight (weight with an empty payload) of the vehicle.

Based on analysis done in support of the Phase 1 heavy-duty vehicle regulation, roughly 30 percent of the total miles driven by tractor-trailers in the United States are done at the permissible weight limit ("weighing-out"), while the remaining 70 percent of miles are driven when the trailer is at its volumetric limit ("cube-out"), carrying a partial load, or empty ("deadheading") (Lowell and Balon 2009). In the case where a vehicle weighs out, reduced curb weight gives the operator the opportunity to increase the payload, thus decreasing the payload-specific fuel consumption, which is the amount of energy (or equivalent emissions) required to move a unit of payload over a unit distance (i.e., gallons or grams per ton-mile). Returning to the example in Figure 2-1, for a fully loaded (80,000 lbs. GVWR) tractor-trailer traveling at constant highway speeds, reducing the tractor-trailer empty weight by 1,000 lbs. and substituting an equivalent payload would yield approximately a 2 percent reduction in payload-specific fuel consumption (Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles 2010). In the case where a tractor-trailer cubes out, the use of lightweight materials makes the loaded vehicle weigh less than it otherwise would, and so less energy is required to accelerate the vehicle and overcome rolling resistance forces. Further, for both weigh-out and cube-out conditions, the use of lightweight materials can help to offset in the additional mass that may be imposed by aerodynamic devices or other fuel-saving technologies.

The development and deployment of lightweight materials in tractors are not discussed in this report. However, vehicle manufacturers are currently offering lightweight alternatives for a number of structural and body components in commercial products. Moreover, research in this area is driving advancements, many of which are highlighted in the U.S. Department of Energy's (DOE) SuperTruck Program, which will be discussed in more detail below. To recognize and promote the commercial availability of lightweight materials in tractors, the U.S. Phase 1 fuel efficiency and GHG regulation credits the use of certain substitute materials as a compliance mechanism for the tractor standard.

For many different types of trailers, there are models currently available that make use of lightweight materials for various components, and customers have options for additional lightweight features or packages. As is discussed in the following chapter, the van trailer market is dominated by three manufacturers, which together account for more than 80 percent of sales (R. L. Polk & Co. 2012a). These manufacturers have employed composites or aluminum in place of plywood lining and steel sheet metal for side wall panels and rear doors in their premium dry-freight van product lines, as summarized in Table 2-2. Aluminum wheels and wide-base tires are common optional features for both van and non–van trailers. The use of aluminum in place of steel in wheels provides a weight savings of roughly 30 pounds per wheel, which for a van trailer with eight standard dual tires is a total reduction of 240 pounds (Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles 2010). For

WBS tires, the approximate weight savings is 175 pounds per axle, or 350 pounds total for a standard two-axle trailer (Lew 2012).

According to a report from the National Academy of Sciences (Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles 2010), the use of wood in trailer side paneling is diminishing, but there is currently no publicly available data as to the degree of penetration of aluminum or composite paneling in the market for new trailer sales or the purchase price premium that these lightweight materials command.

Table 2-2: Examples of commercially available dry-van trailers using lightweight materials

Manufacturer	Product Name	Materials	
		Side Walls	Rear Doors
Wabash	**DuraPlate XD-35**	Composite	Composite
Great Dane	**Champion SE**	Aluminum	Steel
Utility Trailer	**4000D-X Composite**	Composite	Steel

Sources: Great Dane, n.d.; Utility Trailer Manufacturing Company, 2013; Wabash National Corporation, 2013

The U.S. DOE's SuperTruck Program is a collaborative research and development program aimed at bettering the efficiency of tractor-trailers. The program is split into four distinctive research projects, which are lead by Cummins, Daimler Trucks North America, Navistar, and Volvo. One of the principal goals of the SuperTruck program is to develop a tractor-trailer that can achieve 50 percent greater freight efficiency (payload tons per gallon) over a defined drive cycle as compared to a model-year 2009 baseline. An additional target is to improve freight efficiency by 68 percent over a defined 24-hour real-world cycle that is meant to represent typical long-haul operations. The project began in 2010, and the teams are on schedule to complete the demonstrations and analysis in 2014/2015.

All four SuperTruck teams have a comprehensive research and development approach that includes improvements to virtually every technology area, including the engine, drivetrain, powertrain integration, aerodynamics, rolling resistance, idling reduction, and vehicle frame lightening. Looking specifically at mass reduction strategies, all of the teams are employing lightweight materials in the tractor design. From the latest SuperTruck project review, two of the teams have highlighted the weight savings that are specific to the trailer. The lead for the Cummins team on trailer technologies is Utility Trailer, which has cut out roughly 2,500 pounds through the use of lightweight materials and advanced design concepts. The team estimates that this reduction in the trailer curb weight and the corresponding expansion in payload results in an overall increase in freight efficiency of nearly 8 percent. Looking at the tractor-trailer in its entirety, the net weight reduction after accounting for the additional bulk of the aerodynamic and idling management equipment yields a greater than 3 percent improvement in freight efficiency. The trailer manufacturer project partner for the Navistar team is Wabash, which reports that trailer lightening results in roughly 1,200 pounds saved for payload capacity. To put these weight reduction values in context, a conventional trailer weighs about 14,000 pounds.

2.7 EFFICACY OF TECHNOLOGIES

There are not yet precise, representative real-world measurments of the fuel consumption reduction for the technologies depicted above. Measurement techniques will need to evolve and improve as more technologies emerge and are tested. As a result, projected fuel consumption benefits are necessarily approximate. For example, Bachman, Erb, and Bynum (2005) compared the fuel use of a tractor-trailer with and without trailer aerodynamic devices by means of track testing. The devices showed improvements at 55 mph and 65 mph peak speed operation that did not on average suggest a consistent change in drag coefficient. Repeat runs at 55 mph indicated a high variability in measured fuel economy data. However, the data did evidence a substantial aerodynamic benefit to these trailer devices. A study of European trucks by Hausberger, Rexeis, Blassnegger, and Silberholz (2011) found that measured gains differed when constant-speed testing was employed versus coast-down testing. However, improvement overall was verified. Wood (2012) demonstrated on a test track repeatability in examining side skirts of various designs, as well as data differences between discrete skirt configurations. Increased accuracy in measurement will continue to provide an improved understanding trailer aerodynamic device benefits.

In addition to these studies, there are numerous other testing projects that have measured the fuel consumption potential of various aerodynamic and tire technologies for trailers. Many of these studies were catalogued by TIAX as part of its analysis of fuel-saving technologies for medium- and heavy-duty vehicles (Kromer, Bockholt, and Jackson 2009). This TIAX research was part of a larger effort coordinated by the National Academy of Sciences to assess current and near-term (2015–20) technologies for increasing efficiency in the commercial vehicle sector (Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles 2010).

Based on a review of the literature as well as interviews with various industry stakeholders, the TIAX and NAS studies identified reasonable ranges for the fuel consumption benefits of a number of trailer aerodynamic devices. However, the actual efficacy of a given technology is linked to a host of different considerations such as the design and installation of the technology, vehicle drive cycle, grade, and payload. As such, the fuel consumption ranges shown in Table 2-3 are approximations meant to represent average fuel benefits for the long-haul trucking sector. Generally, the expected fuel savings from the individual aerodynamic devices is between 2 percent and 6 percent for each of the three primary loss areas: the tractor-trailer gap, the trailer roof/sides/underbody, and the trailer rear end. When combining technologies targeting two of three trailer loss areas (i.e., a partial aerodynamic package), estimated efficiency gains are between 5 and 6 percent for long-haul operations. If a device is used for all three of the loss regions (a full aerodynamic package), estimated fuel savings increase to up to 9 percent.

Table 2-3: Fuel reduction potential and costs of various trailer technologies

Trailer Technology	Potential fuel consumption reduction	Cost for one trailer	Cost for three trailers
Partial skirts (4 – 6 m)	3 – 4%	$1,500 – $2,000	$4,500 – $6,000
Full skirts (7 – 9 m)	4 – 6%	$2000 – $4,000	$6,000 – $12,000
Partial gap reducer (cuts gap ~ in half)	1 – 2%	$800 – $1,000	$2,400 – $3,000
Full gap reducer (fully closes gap)	2 – 3%	$1,000 – $1,500	$3,000 – $4,500
Boat tails	4 – 6%	$1,500 – $2,000	$4,500 – $6,000
Low rolling resistance tires	1 – 2%	$30/tire ($240 total)	$720
Improved wide-base single tires + aluminum wheels	4 – 6%	$900	$2,700
Automatic tire inflation	0 – 1%	$300 – $400	$900 – $1,200
Partial aero package–partial skirts, and partial gap reducer	4 – 8%	$3,000	$9,000
Full aero package–full skirts, boat tail, and full gap reducer	7 – 11%	$4,000	$12,000

Based on Kromer, Bockholt, and Jackson, 2009; Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, 2010

The right-hand columns of Table 2-3 summarize the cost estimates from the TIAX and NAS studies for each of the trailer technologies. These cost estimates are largely based on data from 2009 and earlier, and the current costs for these technologies may already be significantly lower, thanks to far more market entrants driving cost competition and much higher deployment volumes reducing cost per unit. The far-right column shows the costs to implement each technology for three trailers. As discussed in more detail in the following chapter, there are more trailers in the United States than there are tractors by roughly a factor of three. Therefore, in theory, to reap the full benefits of introducing trailer technologies, upgrades must be made to three trailers for every tractor. This three-to-one ratio methodology is used in both the TIAX and NAS studies to assess the cost-effectiveness of aerodynamic and rolling resistance technologies for tractor-trailers. Scrutinizing sales and in-use registration data for trailers and tractors (see Chapter 3) may challenge this assumed ratio of three to one. However, the ideal metric for analyzing the cost-effectiveness of tractor and trailer technologies is vehicle miles traveled (VMT), and further research is needed to understand better how VMT and equipment lifetimes for trailers compare to those of tractors.

3 TRAILER MARKET

This chapter provides an overview of the U.S. commercial trailer market, including total market size, the types of trailers sold, major trailer manufacturers, new and used trailer pricing, characteristics of trailer users, and market barriers for trailer technology deployment.

3.1 TOTAL MARKET SIZE

In 2009, there were approximately 5.7 million commercial trailers[11] registered in the United States. (Bureau of Transportation Statistics 2010). In 2011, approximately 176,000 new commercial trailers (between 24 feet and 65 feet) were registered, up from 108,000 in 2010 and 79,000 in 2009 (R. L. Polk & Co. 2012). Annual new trailer registrations in 2009 were the lowest in more than 20 years; since the crisis of 2008, new trailer registrations have been less than half of prerecession totals. During the late 1990s and early 2000s new trailer registrations were generally between 240,000 and 300,000 units per year. The drop-off in new trailer registrations between 2008 and 2010 is consistent with a similar reduction in registrations of new Class 8 tractors during that time period. New truck sales also started to pick up in late 2010 and 2011, after bottoming out in 2009.

In 2009, there were 1.8 million Class 8 tractors registered in the U.S (Bureau of Transportation Statistics 2010), so there are about three trailers in use for every tractor. There is currently limited data on the total vehicle miles traveled (VMT) for tractors and trailers individually, so it is difficult to ascertain whether or not this three-to-one ratio is a reasonable approximation for use in cost-effectiveness calculations for trailer technologies. The ratio of trailers to tractors varies significantly by company and by the type of freight carried. Many general freight carriers, which primarily use dry-van and refrigerated-van trailers, operate with 2.5 to 3.5 trailers per tractor, but some have as many as seven trailers for each tractor (Bearth 2009). Carriers that use specialty trailers—for example, lowboys, tank trailers, and grain trailers—sometimes operate with fewer trailers per tractor.

Over the past five years the ratio of annual new trailer registrations to new tractor registrations has varied from 1.17 to 2.18 (R. L. Polk & Co. 2012). This is in line with historical norms; since 1986 an average of 1.73 new trailers have been registered each year for every new tractor (R. L. Polk & Co. 2012).

3.2 TRAILER TYPES

Figure 3-1 provides a summary of the average number of new commercial trailers registered annually over the past nine years, by type and length, based on data from R. L. Polk & Co. (2012).

As shown, 67.7 percent of all new trailers registered were van-type trailers, including dry vans and refrigerated vans. The second most numerous trailer type was the flatbed, including drop-decks (9.0 percent), followed by container chassis used to carry intermodal containerized freight (6.7 percent), grain trailers (3.3 percent), dump trailers (2.9 percent), and tank trailers (2.4 percent). The category “other” in Figure 3-1 includes

11 Data are from the Department Transportation, Bureau of Transportation Statistics. According to BTS, “The completeness of data on trailer registrations varies greatly among states. Data are reported to the extent available and, in some cases, are supplemented by Federal Highway Administration estimates.”

low-bed trailers, livestock trailers, hopper trailers, pneumatic tanks (dry bulk), beverage trailers, logging trailers, and others—together, these types account for only 8 percent of all new trailer registrations.

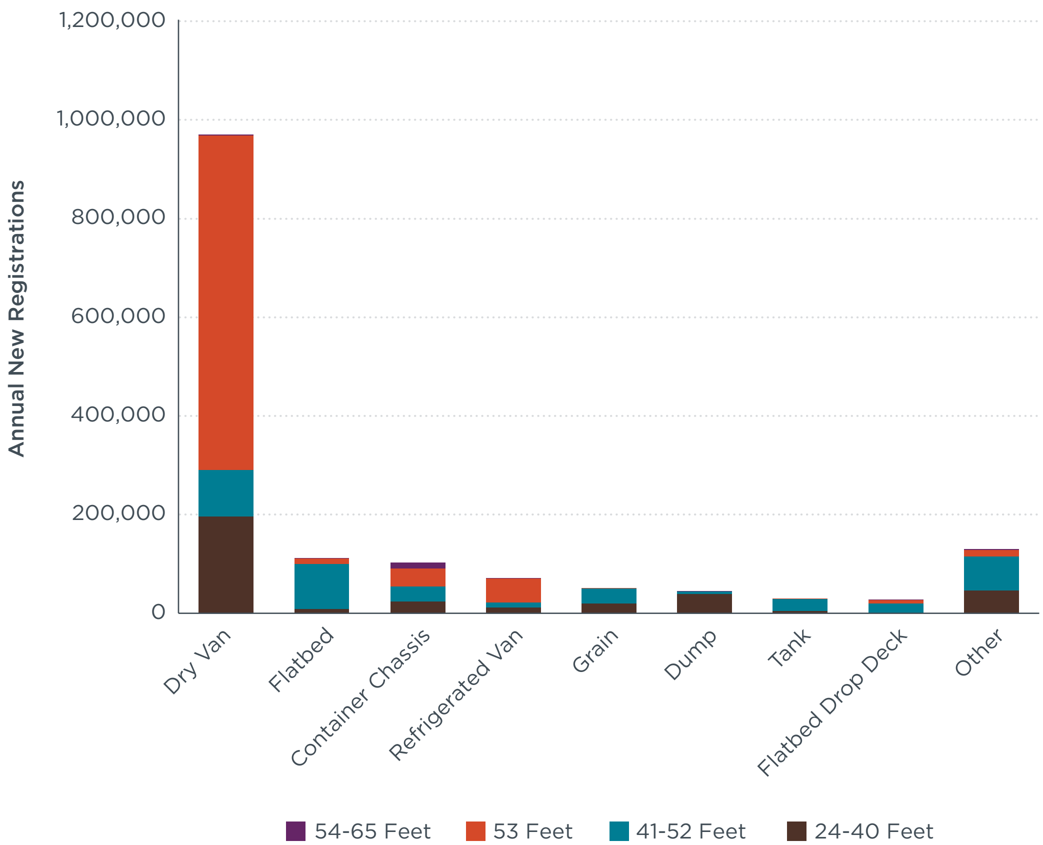

Figure 3-1: Average Annual U.S. New Commercial Trailer Registrations, by Type and Size, 2003 to 2011

Based on data from R. L. Polk & Co., 2012

U.S. commercial trailers typically range in length from 24 to 65 feet. Seventy percent of dry vans and 67 percent of refrigerated vans are 53 feet long, while most other types of trailers are typically shorter: 80 percent of flatbeds, 70 percent of low-beds, 86 percent of hopper trailers, and 77 percent of tank trailers are between 40 and 52 feet in length. Most dump trailers, beverage trailers, logging trailers, and livestock trailers are less than 40 feet long. Thirty-five percent of container chassis are 53 feet long; 29 percent are between 40 and 52 feet long; 23 percent are shorter than 40 feet; and 11 percent are longer than 53 feet. Slightly more than 1 percent of all commercial trailers are longer than 53 feet; of these, the majority are container chassis.

Figure 3-2 provides a summary of average annual new trailer registrations by type between 2003 and 2007 (prerecession) and between 2008 and 2011 (postrecession). During both time periods the new trailer market was dominated by van-type trailers, which accounted for approximately 67 percent of new trailer registrations.

Since the recession of 2008 there have been more significant shifts in specialty trailer markets, likely in response to changes in the economy. Despite a 46 percent drop in total new trailer registrations, average annual registrations of new grain trailers and pneumatic tank trailers actually rose from 2008 to 2011 compared with the prerecession period. Between 2003 and 2007 grain trailers accounted for only 2.0 percent of new trailer registrations, but they constituted 6.2 percent of new trailer registrations between 2008 and 2011. Tank and pneumatic tank trailers, hopper trailers, and livestock trailers also increased their market share but by smaller amounts. Dump trailers and flatbeds lost market share from 2008 to 2011 compared with the prerecession period.

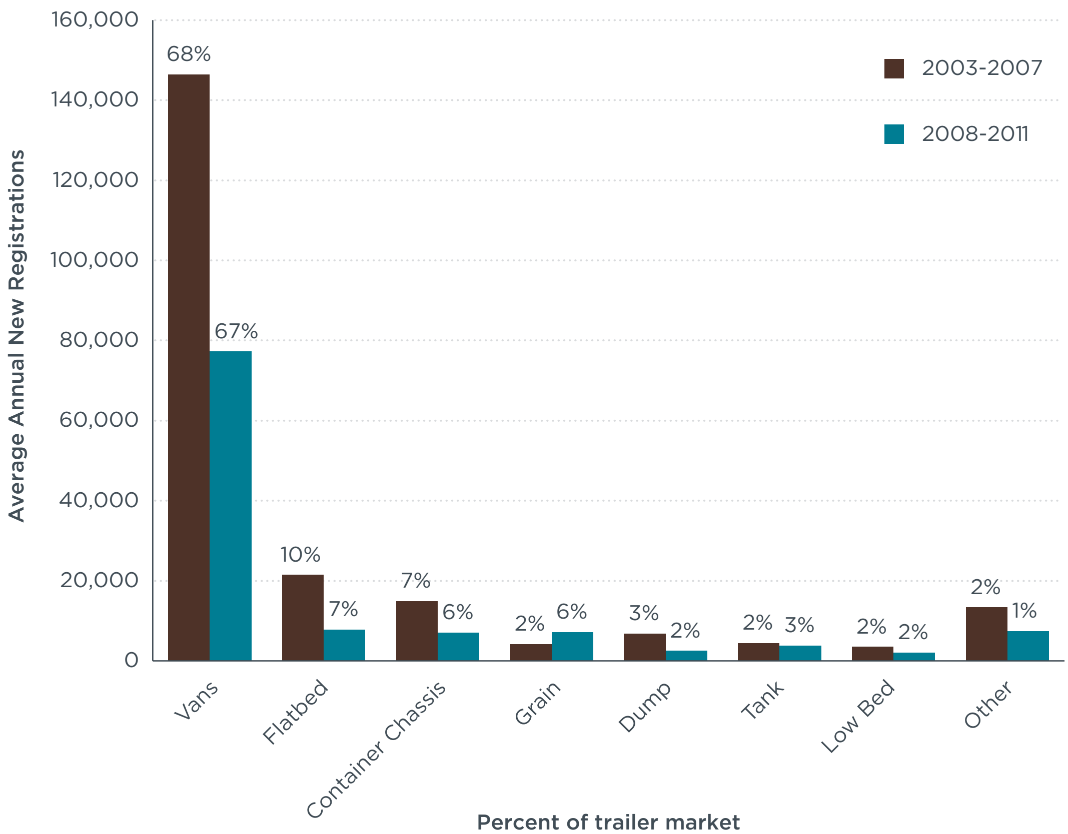

Figure 3-2: Average annual trailer registrations by type for 2003 to 2007 and 2008 to 2011
Based on data from R. L. Polk & Co., 2012

3.3 TRAILER MANUFACTURERS

Table 3-1 shows manufacturer market shares of new commercial trailers registered in the past four years (R. L. Polk & Co. 2012). As shown, the U.S. trailer manufacturing market is really two markets—one for van-type trailers and another for specialty trailers—each with very different players and market dynamics.

Table 3-1: Manufacturer market shares for the entire trailer market, 2008 to 2011

Trailer manufacturer	Average Annual New Registrations	Market Share	Products
Wabash National	23,303	20.2%	Van, refrigerated van, flatbed, tank
Utility Trailer	20,615	17.9%	Van, refrigerated van, flatbed
Great Dane	19,268	16.7%	Van, container chassis, flatbed
Hyundai	7,153	6.2%	Container chassis
Stoughton Trailers	4,621	4.0%	Van
Timpte	4,141	3.6%	Grain
CIMC USA	4,014	3.5%	Container chassis, refrigerated van
Vanguard National	3,527	3.1%	Van, container chassis
Wilson Trailer	1,563	1.4%	Grain, flatbed, Drop-deck flatbed
Transcraft Corporation	1,455	1.3%	Flatbed, drop-deck flatbed
Remaining manufacturers	17,553	22.1%	-
Top 2	43,918	38.2%	
Top 5	74,960	65.1%	
Top 10	89,660	77.9%	

Based on data from R .L. Polk & Co., 2012a

As mentioned, about two-thirds of new trailers registered annually are van-type trailers (dry van and refrigerated van). Manufacturing of these types of trailers is dominated by three companies: Great Dane Trailer, Wabash National, and Utility Trailer Manufacturing. Together, these three companies manufactured 79 percent of the new van trailers registered in the past four years and 55 percent of all newly registered trailers. These three companies primarily manufacture van-type trailers, though Utility and Great Dane also produce significant numbers of flatbeds and container chassis. None of these companies produce specialty trailers.

Over the most recent four years, shares in the total trailer market for each of these three companies ranged from 17 to 20 percent, and their average annual production hovered between 19,000 and 23,000 trailers.

By comparison, between 2006 and 2010 just four manufacturers accounted for more than 99 percent of U.S. Class 8 truck sales[12] (including tractors), with the market share for each ranging from 19 to 33 percent. These manufacturers are Daimler, PACCAR (including the Peterbilt and Kenworth brands), Navistar, and Volvo (including the Volvo and Mack brands). In 2010, each of these manufacturers sold between 19,000 and 36,000 Class 8 trucks[13] (Davis, Boundy, and Diegel 2012).

12 Class 8 trucks are trucks with a gross vehicle weight rating (GVWR) greater than 33,000 pounds.

13 Beginning in 2007, U.S. Class 8 truck sales fell dramatically compared with prior years, which is attributable to the recession and slow recovery. Total sales in 2010 were only 38 percent of sales in 2006.

The next seven largest trailer manufacturers are Hyundai Translead, Stoughton Trailers, Timpte, CIMC Trailers, Vanguard National, Wilson Trailer, and Transcraft. Stoughton and Vanguard produce primarily van trailers; Hyundai and CIMC, primarily container chassis; Timpte and Wilson, mainly grain trailers; and Transcraft, flatbeds for the most part. Over the past four years each of these manufacturers had less than a 6 percent share of the entire trailer market and average annual production of fewer than 7,000 trailers.

Manufacturing of specialty trailers is more fragmented than manufacturing of van trailers. Between 2008 and 2011 there were 59 different manufacturers with a top-10 market share for at least one type of trailer, but other than the ten companies mentioned already, none of them had more than a 1 percent share of the total trailer market, and the vast majority of them produced, on average, fewer than 500 trailers annually. Specialty trailer manufacturers typically concentrate on only one type of trailer, and these specialty trailers are produced in much lower annual volumes than van-type trailers.

Even with the large number of manufacturers in the field, most specialty trailer segments are highly concentrated, with the top manufacturer holding at least a 25 percent market share and the top three manufacturers accounting for more than 70 percent of the market.

There have been significant changes in the commercial trailer market in recent years: 22 manufacturers that had a top-10 market share in at least one specialty trailer market between 2003 and 2007 did not retain it between 2008 and 2011. On the other hand, 15 manufacturers that did not have a top-10 market share in any specialty markets between 2003 and 2007 gained enough to achieve top-10 presence between 2008 and 2011.

The most eye-opening change has been the sudden appearance of the Chinese manufacturer CIMC Trailers in the U.S. market. Before 2008, CIMC sold virtually no trailers in the United States, but between 2008 and 2011 it was the seventh-largest manufacturer, with a 57 percent market share in container chassis and average annual sales of 4,000 trailers. The spike in sales of grain trailers between 2008 and 2011 also moved both Timpte and Wilson Trailer into top-10 manufacturer status for the overall trailer market, displacing Cheetah Chassis, Strick, and Fontaine Trailer. Cheetah Chassis produces mostly container chassis, while Strick makes largely van-type trailers, and Fontaine builds flatbeds.

According to the U.S. Census Bureau, in 2010, there were a total of 402 companies engaged in "truck trailer manufacturing" (U.S. Census Bureau 2012b). Of these, 44 percent were corporations, 43 percent were S corporations, 10 percent were partnerships, and 5 percent were individual proprietorships (percentages add to greater than 100 due to rounding). The vast majority of these companies are modest in size and are in fact small enough to be considered "small businesses" under the definition established by the federal Small Business Administration (SBA), which categorizes by the maximum number of employees, currently set at 1,000 for heavy-duty vehicle manufacturing and 750 for engine manufacturing (U.S. Environmental Protection Agency 2011). In 2010, 77 percent of the companies involved in truck trailer manufacturing employed fewer than 50 people, and 98 percent employed fewer than 250. Only four companies employed more than 500 people and were thus considered by SBA *not* to be small businesses. These four companies are Wabash National, Utility Trailer, Great Dane Trailer, and Hyundai Translead. The fifth-largest trailer manufacturer, Stoughton Trailers, employed 1,200 people at its peak in 2006. After the 2008 recession cut deeply into trailer sales, its workforce dropped to 250 in 2009. With the increase in trailer sales since 2010, its workforce rebounded to just a bit less than 500 at the end of 2010 and to 800 at the end of 2011 (Duwe 2012). The Stoughton example offers some precaution about the volatility inherent in the use of the number of employees as a criterion to determine which companies count as "small."

3.4 NEW TRAILER PRICING AND USED TRAILER VALUES

As shown in Figure 3-3, new 53-foot dry-van trailers typically cost between $22,000 and $27,000 (Price Digests 2012a). Features that increase the cost toward the high end of this range include air ride suspension, insulation, roll-up rear doors, side doors, and stainless steel nose and end caps. The "Max Specification" column in Figure 3-3 represents a van trailer with these additional features. Shorter trailers (45- or 48-foot) typically cost $2,000–$3,000 less. Five-year-old dry-van trailers can be purchased for around two-thirds the cost of new ones (approximately $15,000), while 10-year-old dry vans can be had for about one third the cost of new ($8,400 or so). A typical new 53-foot refrigerated-van trailer costs between $47,000 and $54,000, and the features that increase the cost are the same as for dry vans. Shorter refrigerated vans (45- or 48-foot) typically cost $3,000 to $5,000 less than 53-foot refrigerated trailers.

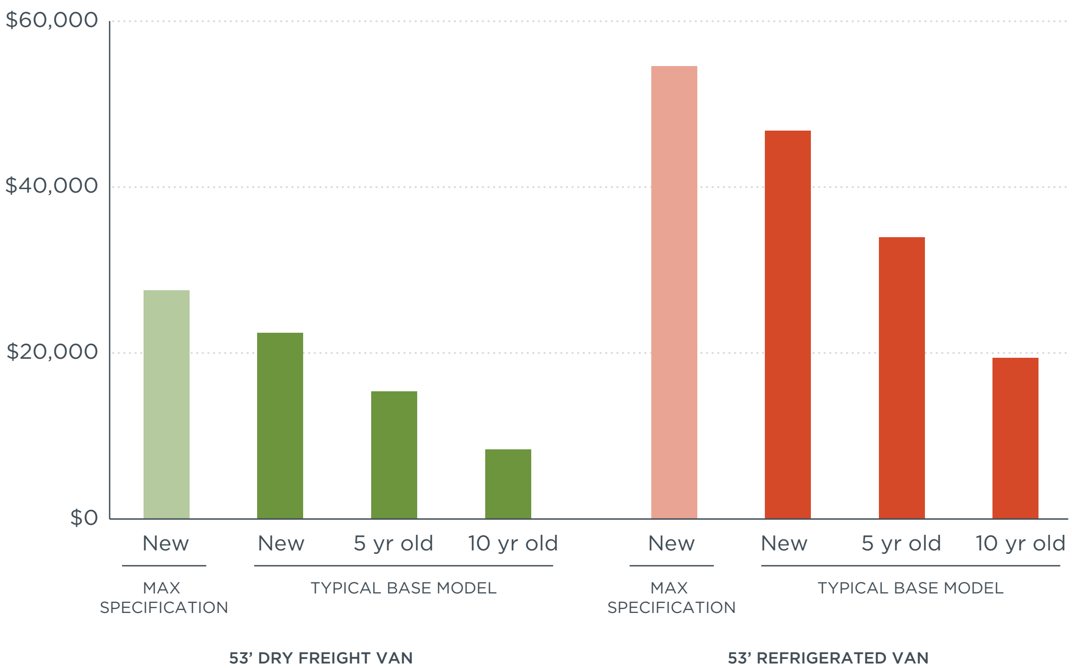

Figure 3-3: Typical Prices for New and Used Van-type Trailers
Based on data from Price Digests, 2012a

The purchase price of a new Class 8 tractor, of the type used to haul commercial trailers, ranges from $103,000 to $116,000 (Price Digests 2012b).[14] The purchase price of a new dry-van trailer is therefore close to 20 percent of the purchase price of a new truck to pull it, while the price of a new refrigerated-van trailer is about 50 percent of the cost of a new truck, and a new stainless steel tank trailer can be 80 percent or more of the cost of a new truck.

14 Prices quoted are for 2012 model-year trucks during the time period April 1 to June 30, 2012, and represent retail sales prices for the International 9000 series, Kenworth T800, Volvo VNL 670 series, Freightliner Coronado, and Peterbilt 387 tractors, all with a high-roof sleeper cab.

A fleet that operates with three dry-van trailers for every tractor will have approximately 60 percent as much capital invested in trailers as it has invested in trucks. Assuming this same three-to-one ratio, fleets that operate with refrigerated-van or tank trailers may have almost as much capital invested in trailers as in trucks.

See Figure 3-4 for a comparison of the change in value of trucks and dry-van trailers over time (Price Digests 2012a; Price Digests 2012b).[15] As shown, trucks tend to lose their value much more quickly than dry-van trailers. The value of a five-year-old truck is about 40 percent of the value of a new truck, while the value of a five-year-old dry van trailer is about 70 percent of that of a new one. The value of a 10-year-old truck is only about 10 percent of the value of a new truck, while that of a 10-year-old dry-van trailer is still about 40 percent of what a new trailer is worth. Even after 17 years in service, dry-van trailers retain 25 percent of the value of a new trailer. Other types of trailers—for example flatbed, dump, grain, and tank trailers—retain an even greater percentage of their value over time than dry-van trailers.

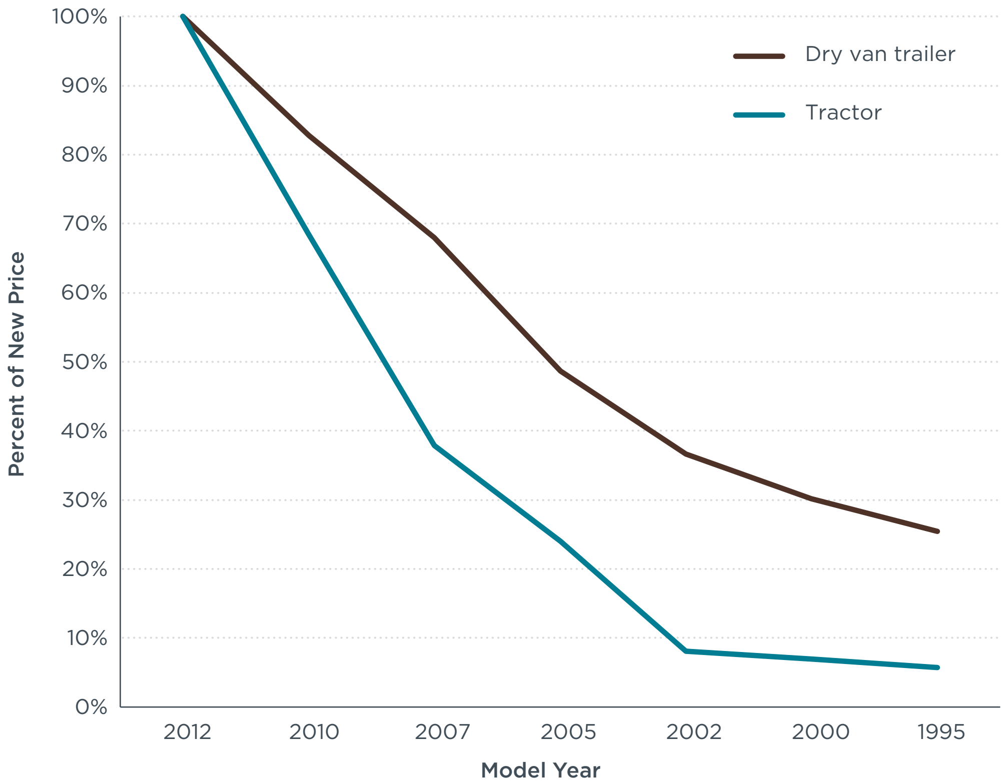

Figure 3-4: Change in Value of Commercial Tractors and Trailers over Time
Based on data from Price Digests, 2012a; Price Digests, 2012b

3.5 TRUCK AND TRAILER FLEET TURNOVER

According to the latest Vehicle Inventory and Use Survey from 2002 (it was subsequently discontinued) that was conducted by the U.S. Census Bureau, heavy tractor trucks typically travel about one million miles before being retired (Vehicle Technologies

15 This chart is based on listed retail sale prices for 1995, 2000, 2002, 2005, 2007, 2010, and 2012 model-year Great Dane 48-foot dry-van trailers and Peterbilt 387 tractors with a high-roof sleeper cab, during the time period April 1 to June 30, 2012.

Office 2005). While individual trucks may in fact stay in service for up to 30 years, their annual mileage falls off significantly after about 15 years, and some 80 percent of total lifetime mileage is accumulated in the first 13 years. This means that the tractor fleet has an effective turnover rate of 6 to 8 percent per year.

Given that there are around three trailers in use for every tractor, trailers typically accumulate mileage much more slowly than trucks, and they therefore have a much longer life. There is less empirical data available about commercial trailer lifetimes than truck lifetimes, but the common wisdom within the industry is that trailers often have an effective life of 30 years or more. This is supported by available data on used trailer values, shown above in Figure 3-4. As mentioned, used trailers hold their value, relative to the cost of a new trailer, much longer than trucks do, indicating a longer effective life. In addition, while the in-use trailer fleet is roughly three times as large as the in-use truck fleet, annual new trailer sales have historically been less than twice annual new truck sales (R. L. Polk & Co. 2012). Between 2007 and 2011, the total number of new commercial trailer registrations was slightly more than 50 percent higher than the number of Class 8 tractor registrations (R. L. Polk & Co. 2012). Available evidence indicates that the annual turnover rate for commercial trailers is only about half the rate for trucks, or about 3 to 4 percent per year.

3.6 TRAILER USERS

Commercial trailers are generally used to carry freight of various kinds. They are used both by for-hire carriers, whose primary business is to carry freight for others for a fee, and by private companies that own their own trucks and carry some or all of their own freight but do not contract out their services to other companies.

According to the U.S. Census Bureau, in 2007, 70 percent of the total tonnage of freight, and 40 percent of the total ton-miles of freight in the United States were carried exclusively by truck (U.S. Census Bureau and Bureau of Transportation Statistics 2010). For-hire carriers moved 46 percent of this tonnage and operated 79 percent of the ton-miles, while private fleets carried the rest. The average miles per shipment for for-hire carriers that year was 599 miles, while it was only 57 miles for private fleets.

In 2010, there were 108,000 for-hire trucking firms in the United States (U.S. Census Bureau 2012a). Two-thirds of these firms were general freight carriers, which typically use van-type trailers, and the rest were specialized carriers that can operate both vans and specialty trailers. Of the general freight carriers, 80 percent functioned primarily as long-distance haulers, and 20 percent focused primarily on local and regional deliveries. Of these 108,000 for-hire carriers, 65 percent have fewer than five employees and 98 percent have fewer than 100 employees. There are only about 40 for-hire freight haulers with more than 1,000 employees, but these companies employ almost 7 percent of the industry's workers (U.S. Census Bureau 2012a).

In addition to the for-hire carriers, there are more than 130,000 companies that operate private freight-hauling fleets. Like for-hire fleets, many of these private fleets are small—approximately 75 percent of them operate 10 or fewer trucks (Reece 2009).

See Figure 3-5 for a list of the twenty-five largest private and for-hire fleets in the country, ranked by the number of commercial trailers that they own (R. L. Polk & Co. and TMW Systems 2012a; R. L. Polk & Co. and TMW Systems 2012b). Also shown in Figure 3-5 is the number of tractors that each company owns or controls. As shown, the largest fleet in the country is for-hire package carrier FedEx, which owns 80,000 trailers and 22,800 tractors. The second-largest is the private fleet owned by Wal-Mart Stores, which has 55,000 company-owned trailers and 6,500 company-owned tractors.[16] Of the twenty-five fleets shown in the figure, four are private fleets and twenty-one are for-hire fleets.

Together, the 100 largest for-hire fleets and the 100 largest private fleets own roughly 905,000 trailers, about 16 percent of the estimated total U.S. commercial trailer population (R. L. Polk & Co. and TMW Systems 2012a; R. L. Polk & Co. and TMW Systems 2012b). These 200 companies also own approximately 303,000 tractors, and control another 71,000 owner-operator and lease-to-own tractors. The overall trailer-to-tractor ratio for these 200 companies is roughly 2.4, and as shown in Figure 3-6, which is a histogram of the trailer-to-tractor ratios, the majority (roughly 40 percent) of these 200 companies have trailer-to-tractor ratios between 1.0 and 2.0. The next most common instance of ratios is the range between 2.0 and 3.0, followed by the range between 3.0 and 4.0.

These 200 companies own or control around 21 percent of the Class 8 tractors registered in the United States. This figure serves as confirmation that a great deal of trucking is conducted by small companies. According to the U.S. Census Bureau, approximately 65 percent of companies in the trucking transportation sector have four or fewer employees (U.S. Census Bureau 2012a).

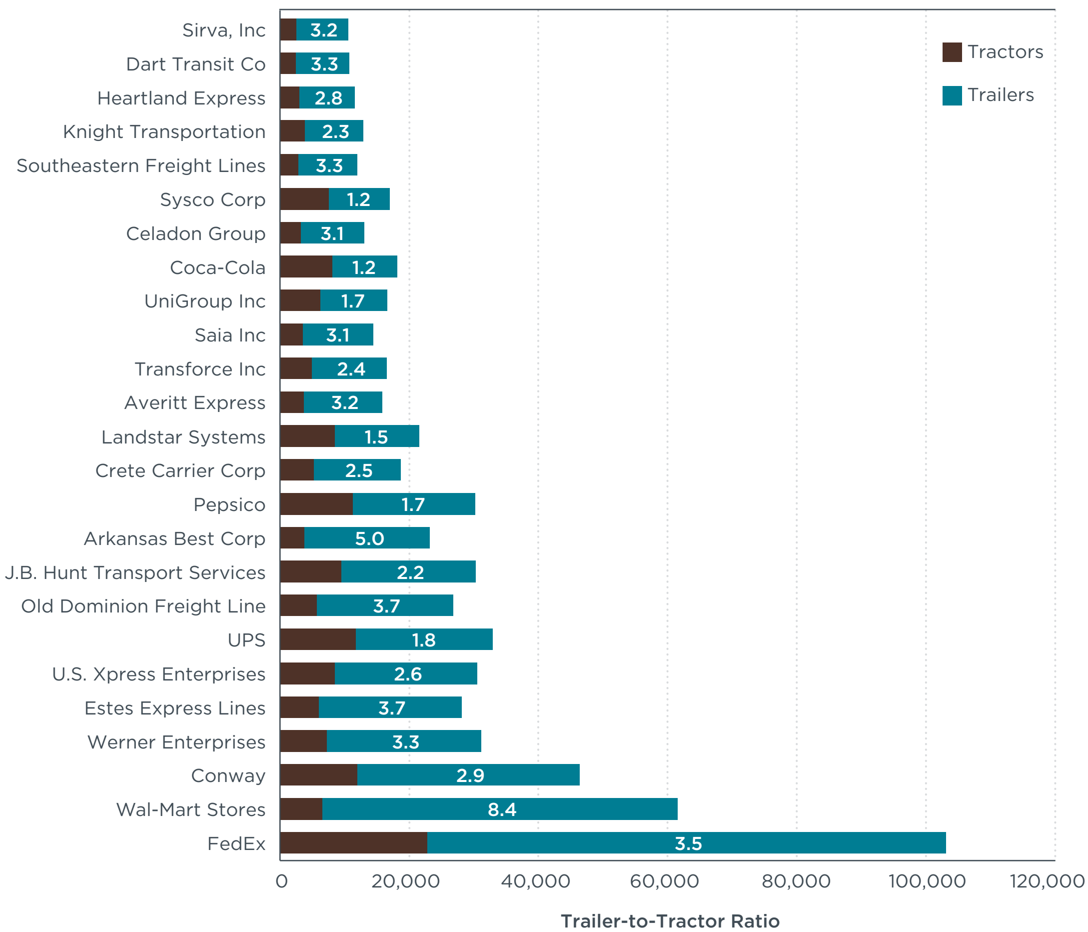

Figure 3-5: Twenty-five Largest Private and For-Hire Fleets by Trailer Ownership
Based on data from R. L. Polk & Co. and TMW Systems, 2012a; R. L. Polk & Co. and TMW Systems, 2012b

16 Wal-Mart also contracts with outside truck drivers (and their tractors) to move its freight. The authors were unable to locate any data estimating the number of truck drivers and/or tractors that are under contract to Wal-Mart at any given time.

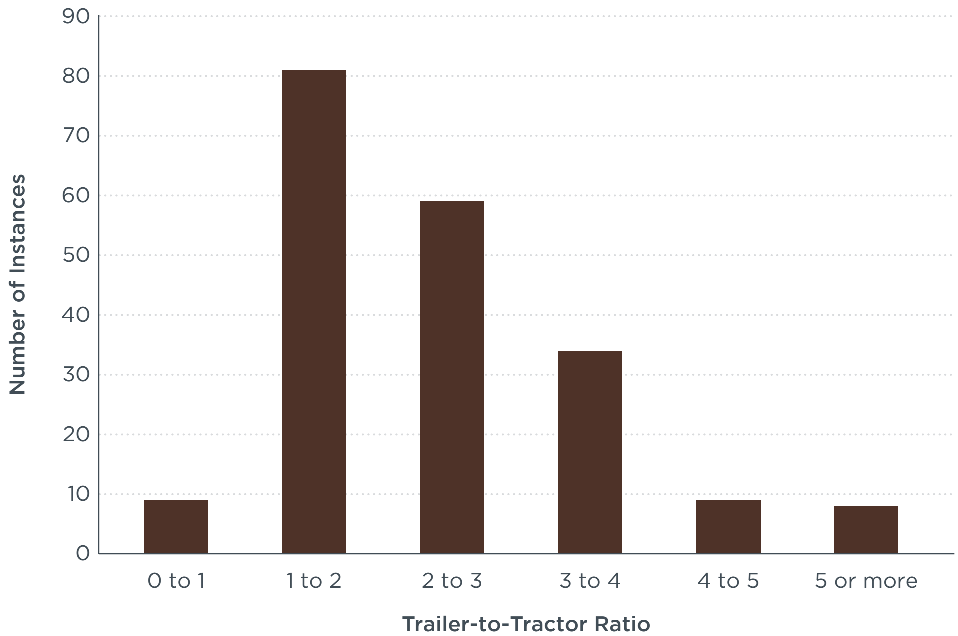

Figure 3-6: Histogram of Trailer-Tractor Ratios for the 200 Largest Private and For-Hire Fleets by Trailer Ownership

Based on data from R. L. Polk & Co. and TMW Systems, 2012a; R. L. Polk & Co. and TMW Systems, 2012b

3.7 BARRIERS TO TRAILER TECHNOLOGY DEPLOYMENT

There are many barriers that have hindered the adoption of a number of fuel-saving trailer technologies, and some of these barriers are interrelated. However, as of this writing, the authors do not have access to detailed sales data regarding these technologies, and, thus, it is difficult to estimate the extent to which the barriers that are described briefly below have prevented their market penetration. Collecting and analyzing trailer-technology-specific sales data is an important area of research in order to understand the state of the market and assess the impacts of the current and potential policy measures targeting trailer efficiency improvements that are discussed in Chapters 4 and 5.

This section provides a summary of some of the impediments to trailer technology deployment. A detailed investigation of market barriers is beyond the scope of this report, but research in this vein is currently being pursued as part of an ongoing ICCT project led by the North American Council for Freight Efficiency and Cascade Sierra Solutions that is exploring the barriers to the development and deployment of fuel-saving technologies for tractor-trailers in the United States. A similar ICCT-funded study of the European on-road freight market was recently completed, and the study's findings that are pertinent to trailers provide additional context for the discussion (Aarnink, Faber, and den Boer 2012).

3.7.1 Financial Constraints, Uncertainty, and Lack of Information

Lack of ready access to a reliable projection of the fuel savings that a technology will provide as well as its overall impact on a fleet's operation may be a deterrent to investment. In some cases this may be attributable to the inability to reach an independent conclusion free of vendor claims; in others, fleet managers might be inclined, in the absence of hard information, to make overly conservative assumptions. Testing and verification of a technology's performance in real-world operation can be an expensive endeavor for freight carriers. Moreover, companies might simply not have the additional capital available to invest in a trailer with fuel-saving technologies that increased the purchase price, or, in the case of an after-market technology, the fleet might not be able to afford any downtime associated with retrofitting.

3.7.2 Split Incentive

Often, the firm that owns the trailer and makes decisions about technology investment is not the same one that operates the trailer and thus would reap the benefits of measures that reduced fuel consumption. In this situation, there is a disincentive for the trailer owner to invest in fuel-saving technologies that represent an additional cost. This *split incentive* is a problem in the on-road freight market, but the extent to which it has impeded adoption of trailer technologies is unclear and is being explored more thoroughly in the ongoing ICCT market barriers research project.

3.7.3 Trailer-to-Tractor Ratio

It is hard to determine a precise ratio of in-use trailers to in-use tractors in North America because many trailers may be used primarily for storage and because there are permanent registration options for trailers (making it hard to know when trailers are taken out of service). However, as mentioned above, it is widely acknowledged that about three in-use trailers exist for every tractor. To equip a trailer fleet with aerodynamic devices is therefore less attractive than to equip a tractor fleet because the annual vehicle miles traveled for trailers will be lower than for tractors. This may be offset, in part, by long in-use trailer life, but distant projections of benefits are typically not attractive to owners.

3.7.4 Inconvenience and Perceived Inconvenience

Certain fuel-saving technologies for trailers may require additional maintenance, affect in-service times, or disrupt operations. This may well be regarded by fleets and their customers as lost hours of productivity. In addition, certain technology features may have limited service networks for repairs or replacement, and that can limit a trailer's availability. Equipment availability is recognized as an important constraint in transportation because it can retard responsiveness to customer needs; adequate spare ratios allow fleets the flexibility they need.

There are many instances in which a technology may represent an inconvenience or compel a change in operations for a fleet. Trailer side skirts may be seen as limiting ready access to the underside of the trailer for inspection or repair, leading to incremental time loss in the eyes of those drawing up personnel schedules. Moreover, skirts or other underbody devices reduce the vehicle's break-over angle and can be damaged on humps or railroad tracks. Whereas they are unlikely to result in high centering (as with lowboy flatbed trailers), they can be damaged under these circumstances. Trailer tail devices, depending on their design, may limit the ability of a truck to back into a narrow space directly up to a dock or may exact additional effort or time spent in opening the trailer rear for the dock. However, for each of these cases there is no reliable assessment of the extent to which the preoccupations are either a real or a perceived influence on adoption. Manufacturers are cognizant of these issues, though, and frequently advertise to dispel these concerns.

3.7.5 Irrelevance or Perceived Irrelevance

Certain operators view trailers other than van or refrigerated trailers as unsuited to aerodynamic surface improvements. In some cases they are correct; in some cases adequate study and design are still lacking; and in other cases certain surfaces may be beneficial. For example, underbody skirts are being added to some tanker, flatbed, and bulk material trailers. The manufacturer Freight Wing suggests that there may be 3 to 6 percent fuel savings as a result, but the detailed studies typical for van trailers are not available in the literature. The web magazine *Bulk Transporter* reports on aerodynamic studies to reduce tanker drag (Bulk Transporter 2009).

3.7.6 Weight Regulations

The aerodynamic designs themselves are sometimes restricted by weight issues. As discussed in Section 2.7, most aerodynamic designs increase vehicle mass. Although their evolution has occurred in conjunction with that of advanced lightweight materials and more sophisticated design, the net negative effect persists. This extra weight detracts from the fuel efficiency of the vehicle by increasing the tire rolling resistance losses, and inertial drag. Added weight will also affect vehicle acceleration and grade-climbing performance. The extent to which the added weight erodes the benefit of lower aerodynamic resistance depends on the vehicle "duty cycle" (how the truck is used), often described in terms of average speed or degree of transient (stop-and-go driving) behavior. At very low speeds the weight will prevail over aerodynamic gain, but most legitimate aerodynamic devices still offer a net positive effect even at moderate speeds.

In some cases, where vehicles are loaded to near their permissible weight limit ("weigh out") rather than cubing out, the weight of the aerodynamic devices can necessitate a lessening of the vehicle payload and, hence, productivity. On most highways the weight limit of a five-axle combination is 80,000 pounds, but the driver must also comply with the statutory federal bridge formula. This implies that no tandem axle pair can carry more than 34,000 pounds, and this may be more restrictive than the 80,000-pound overall limit. The axle load restrictions implied by the bridge formula cause vehicle operators to move the fifth-wheel position and trailer axle. Any added weight on the tractor or trailer is not only an inconvenience but raises the possibility of limiting the load a truck can carry.

4 EXISTING POLICIES THAT TARGET TRAILER EFFICIENCY

There is a mix of policies promoting trailer technologies that promise increased efficiency. These interrelated measures include a national voluntary standard, a California regulation that incorporates provisions for trailers, and small financial incentive programs related to technology procurement.

This chapter describes both voluntary and mandatory programs targeting trailer efficiency as well as the mechanisms through which each policy is stimulating the adoption of technologies that reduce fuel consumption. This discussion of current measures provides context that is fundamental for the analysis of policy options in the following section.

4.1 U.S. EPA SMARTWAY

The SmartWay Transport Partnership is a collaborative voluntary program between the U.S. Environmental Protection Agency (EPA) and the freight industry designed to improve energy efficiency and lower greenhouse gas (GHG) emissions and air pollution. Started in February 2004, the partnership aims to create market-based incentives that challenge shipping and logistics companies to improve the environmental performance of their freight operations. The SmartWay program has served as a model for similar programs in many regions around the world, including Europe, Mexico, and Guangdong province, China.

From its inception, one of the most influential components of the SmartWay program has been its focus on innovative ways of reducing fuel use and emissions from tractor-trailers. Through the program, equipment and vehicle configurations that are tested and verified to have fuel consumption profiles at or below given value are granted a *SmartWay* designation. This designation has a label to signify a technology that increases fuel economy (similar to the U.S. Department of Energy's Energy Saver label for appliances).

There is also a notable tie-in between the voluntary SmartWay and the EPA regulatory GHG and efficiency program for tractor-trailers. The tractor-trailer testing that was conducted within the SmartWay program provided critical data for Phase 1 of the agency's fuel efficiency and GHG regulatory regime for heavy-duty vehicles, particularly for tractor aerodynamic performance. Moreover, the SmartWay program has helped the EPA to forge partnerships among a diverse set of stakeholders, which fostered a fruitful exchange of technical expertise during the rulemaking process for the Phase 1 vehicle regulation.

An important aspect of SmartWay is its independent testing and analysis, which proffer valuable information to SmartWay partners on the emissions reduction performance of various technologies that are on the market. As part of this effort, SmartWay is developing a fuel efficiency test protocol for heavy-duty vehicles that will yield a more robust quantification of the benefits of various designs and technologies. The existing EPA tractor-trailer combination design-based specification was developed on the basis of test results for individual components (e.g., tires, wheels, aerodynamic equipment, auxiliary power units, engines). The EPA, its SmartWay partners, and others are working to transform the SmartWay designation by moving toward a performance-based specification. A performance-based specification would be technology-neutral and able to quantify a broad range of heavy-duty vehicle configurations and applications. In addition, it would more accurately measure emerging technology innovations.

The EPA currently recognizes 18 cab models as being SmartWay tractors (U.S. Environmental Protection Agency 2012). Elements of the SmartWay specification include streamlined, aerodynamic shapes for the mirrors, bumper, and hood, an integrated roof fairing, cab side extenders (or “gap fairings”), and low rolling resistance (LRR) steering and driving tires. By contrast, a “classic”- or “conventional”-style tractor has characteristics that contribute to increased aerodynamic drag during vehicle operation—particularly at highway speeds. Drag-inducing features include the side exhaust stacks, the air filters, an angular front grille and bumper, and the fuel tanks and battery box.

Trailers can achieve SmartWay designation in a number of different ways. First, SmartWay-certified LRR tires must be used, and there is an optional measure to use aluminum wheels (or integrate other lightweight materials into the design) to achieve weight reduction. For aerodynamic improvements, there are five options, each of which is certified to provide 5 percent or greater fuel savings. These options are depicted in Figure 4-1.

As mentioned, the EPA is continuing to examine performance-based testing approaches that may prove more accurate for the fuel consumption benefit estimates. The existing program provides simple percentage figures as estimated benefit levels for the various technologies and technology packages. The exact fuel consumption reduction values from verification testing of individual products are not made publicly available, but, rather, each aerodynamic innovation or reconfiguration is assigned a benefit of 1 percent, 4 percent, or 5 percent, based on the test results. Technologies with test results below 4 percent are validated as a 1 percent fuel-saving technology; those between 4 and 5 percent are verified at 4 percent, and those showing 5 percent or more fuel savings are assigned a value of 5 percent.

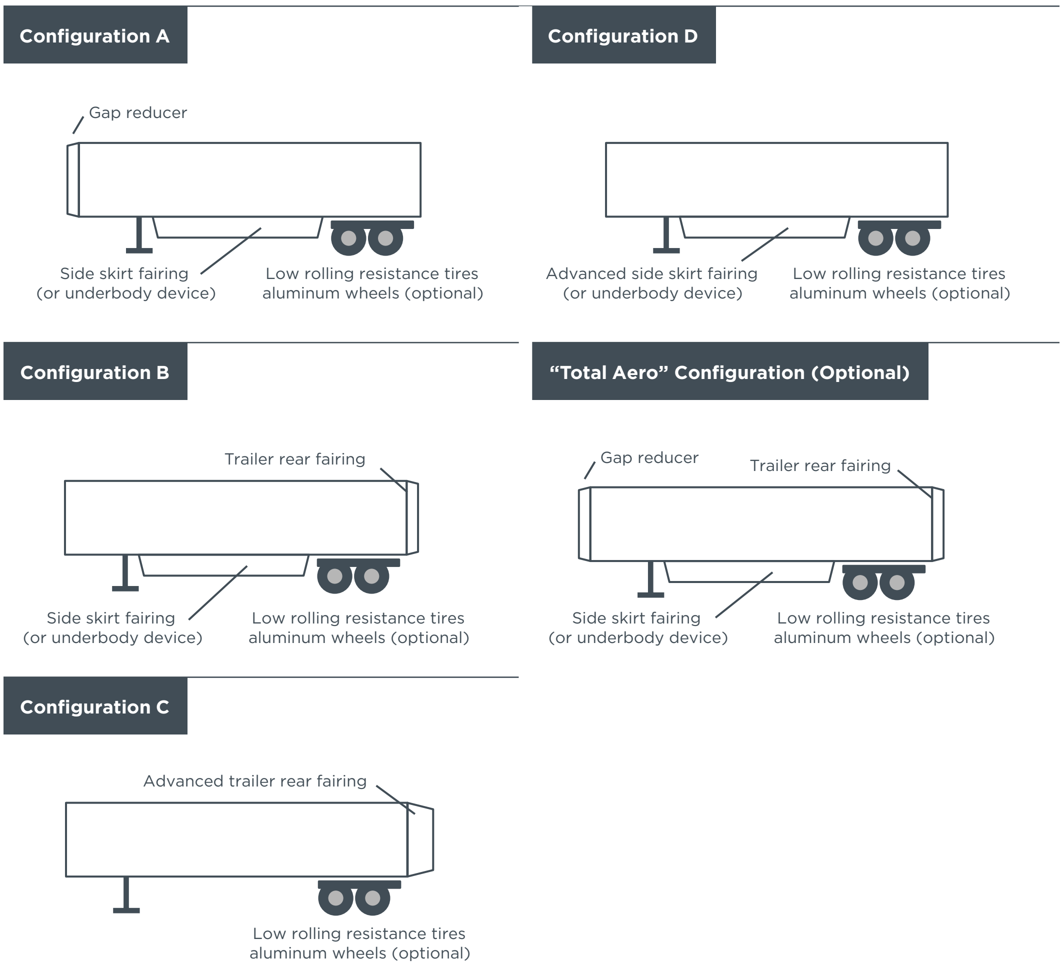

Figure 4-1: SmartWay trailer configurations

According to the SmartWay technology program website (U.S. Environmental Protection Agency 2012), there are 10 manufacturers that offer SmartWay-certified trailers. Seven of the top-20 trailer-selling companies offer SmartWay trailers. However, there are no available data on how many of SmartWay-certified trailers are sold by company, or as a fraction of the overall sales, and no breakdown by original equipment manufacturer (OEM) versus retrofitting.

In addition, there are currently dozens of companies that offer SmartWay-certified aerodynamic equipment. A list of the aerodynamic devices that are currently certified at the 1 percent, 4 percent, and 5 percent fuel consumption reduction levels are given in the Appendix. Data for the overall sales of the SmartWay-certified aerodynamic devices and for sales of each individual SmartWay-certified aerodynamic device, broken down by fuel consumption percentage classification, are not publicly available.

There are 12 companies that sell LRR tires (dual tires or single-wide tires). SmartWay does not offer specific percentage levels of fuel saving for these LRR tire technologies. Data for the overall sales of SmartWay-certified LRR tires and for the sales of each SmartWay-certified LRR tire or tire set by company are not publicly available. According to the EPA, approximately half of the overall tractor-plus-trailer fuel savings from tire improvements, or about 1.5 percent of the total reduction in fuel consumption via SmartWay verification, is contributed by the trailer tires.

4.2 CALIFORNIA TRACTOR-TRAILER GREENHOUSE GAS REGULATION

As part of its efforts to reduce GHG emissions from all sectors of economy, California's Air Resources Board (ARB) has adopted a regulation that aims to increase the efficiency of long-haul tractor-trailers operating in the state. This regulation, which was first proposed in late 2008 and formalized in 2012, has mandatory tractor and trailer equipment specification provisions for the companies that operate tractor-trailers. It requires the use of aerodynamic tractors and trailers that are also equipped with LRR tires. The tractors and trailers subject to the regulation must either use EPA SmartWay-certified tractors and trailers or be retrofitted with SmartWay-verified technologies. California's program is the first in-use greenhouse gas regulation in the world and is estimated to have reduced GHG emissions by 6–10 percent, compared with baseline non-SmartWay equipment for any long-haul tractor-trailer that operates in California. The ARB estimates that roughly 30 percent of all such tractor-trailers in the United States are active in California and are thus subject to the regulation (Air Resources Board 2008).

The regulation affects 53-foot or longer box-type trailers, including both dry-van and refrigerated-van trailers, as well as the heavy-duty tractors that pull these trailers within California. The owners of these types of equipment are responsible for replacing or retrofitting their vehicles and trailers with suitable aerodynamic technologies and low rolling resistance (LRR) tires. All tractor and trailer owners, regardless of where the equipment is registered, must comply with the regulation when operating in California. Equipment dealers that sell vehicles and trailers in California covered by the regulation must provide disclosure about it to the buyer.

Table 4-1 summarizes the trailer requirements of the program and compliance dates for fleets. There are specific requirements for large fleets, which are defined as any fleet operating 21 or more trailers. Fleets consisting of 20 or fewer trailers are regulated under the small fleet provisions. The compliance schedule options for large and small fleets are shown in Table 4-2.

The stipulations of the tractor component of the rule are fairly straightforward. Starting January 1, 2010, model-year (MY) 2011 and newer sleeper tractors must be SmartWay certified, and MY 2011 and newer day cabs must have SmartWay-verified LRR tires. All MY 2010 and older tractors are required to have LRR tires by January 1, 2013.

As with tractors, the requirements of the trailer program are based on the model year and the type of equipment. As shown in Table 4-1, there are unique provisions and compliance deadlines based on whether the trailer is refrigerated or a dry van, as well as on the trailer's model year. The aerodynamic requirements for trailers are given in terms of a percentage: 4 percent or 5 percent. The percentage refers to the SmartWay designation for the certified fuel-savings level of a given piece of equipment. For dry-van trailers requiring 5 percent fuel savings, users can combine a 1 percent certified device with a 4 percent certified device or opt for a 5 percent certified device. Operators of refrigerated trailers are required only to install an aerodynamic device that is certified to the 4 percent level.

Table 4-1: Trailer requirements for the California HD GHG Regulation

Affected Trailers	Requirements	Compliance Date January 1st
MY 2011 and newer dry vans	LRR tires + 5% fuel-saving aerodynamic technologies	2010
MY 2011 and newer refrigerated vans	LRR tires + 4% fuel-saving aerodynamic technologies	2010
MY 2010 or older dry vans	5% fuel-saving aerodynamic technologies	2013
MY 2010 or older dry vans	SmartWay-verified LRR tires	2017
MY 2003–2004 refrigerated vans	LRR tires + 4% fuel-saving aerodynamic technologies	2018
MY 2005–2006 refrigerated vans	LRR tires + 4% fuel-saving aerodynamic technologies	2019
MY 2007–2009 refrigerated vans	LRR tires + 4% fuel-saving aerodynamic technologies	2020

Table 4-2: Large- and small-fleet compliance options for MY 2010 and older van-type trailers

		Percentage of new trailers that must comply						
		2011	2012	2013	2014	2015	2016	2017
Large fleet	**Option 1**	5%	15%	30%	50%	75%	100%	100%
	Option 2	-	20%	40%	60%	80%	100%	100%
Small fleet	**Option 1**	-	-	-	25%	50%	75%	100%

Because of the fairly extensive coverage of this regulation with respect to fleets on the road, the ARB has developed and maintains a widespread outreach and education campaign. During the multiyear regulatory development process, the ARB held numerous public workshops to engage with a host of different stakeholders on a wide range of technical and economic issues. In addition, the ARB continually holds free courses across the state that present information about the program and detailed compliance training for interested parties. The agency has developed a web portal called the *Truck Stop*, where users can navigate to information about all of the state's regulations affecting in-use vehicles and equipment. All of the reporting for the Heavy-Duty (Tractor-Trailer) Greenhouse Gas Regulation (as well as for the Truck and Bus Regulation) can be conducted through the Truck Regulation Upload, Compliance, and Reporting System (TRUCRS) (Air Resources Board 2012).

To help with purchasing equipment that is required under the regulation, both large and small fleets are eligible for incentive funding through the ARB Heavy-Duty Vehicle Air Quality Loan Program, the EPA's SmartWay Finance Program, and the SmartWay Clean Diesel Finance Program. In addition, there are local government agencies and nonprofit organizations that promote SmartWay-verified technologies primarily by helping fleets obtain grants, tax incentives, and low-interest loans to aid in the purchase of emission-reducing and fuel-saving equipment that is needed to comply with California's Heavy-Duty Greenhouse Gas Regulation.

5 POLICY OPTIONS FOR TRAILERS

This chapter assesses some of the regulatory options for increasing the efficiency of trailers. It lays out several policy options to build upon the experiences of the Phase 1 U.S. heavy-duty vehicle regulation to promote the development and deployment of new trailer technologies for increased tractor-trailer efficiency. As discussed previously, trailers are a prominent part of the U.S. EPA SmartWay program and California's Heavy-Duty (Tractor-Trailer) Greenhouse Gas Regulation. However, trailers were omitted from the EPA and NHTSA heavy-duty vehicle GHG and efficiency regulatory standards for new vehicles in the 2018 time frame. This excerpt from the final rulemaking by the EPA and the National Highway Traffic Safety Administration (NHTSA) explains the agencies' justification for omitting trailers from the Phase 1 program:

> *In the NPRM* [notice of proposed rulemaking]*, the agencies discussed relatively conceptual approaches to how a future trailer regulation could be developed; however, we did not provide a proposed test procedure or proposed standard. The agencies proposed to delay the regulation of trailers, as the inclusion would not be feasible at this time due to the lack of a test procedure and the myriad of technical and policy issues not teed up in the NPRM or addressed in comments. Additionally, since a number of trailer manufacturing entities are small businesses, EPA and NHTSA need to allow sufficient time to convene a SBREFA* [Small Business Regulatory Enforcement Fairness Act] *panel to conduct the proper outreach to the potentially impacted stakeholders. As noted earlier, the agencies do not believe it warranted to delay the combination tractor and vocational vehicle standards for the years it will take to resolve these issues. NHTSA and EPA agree that the regulation of trailers, when appropriate, is likely to provide fuel efficiency benefits. We continue to believe that both agencies must perform a more comprehensive assessment of the trailer industry, and therefore that their inclusion at this time is not feasible. Until that time, the SmartWay Transport Partnership Program will continue to encourage the development and use of technologies to reduce fuel consumption and CO2 emissions from trailers.* (U.S. Environmental Protection Agency 2011a)

Now, however, as earlier chapters of this report detail, there are commercially marketable trailer technologies, more is now understood about the trailer market dynamics, and there has been considerable dialogue among various industry and other stakeholders about trailer-related policy.

5.1 RELATIVE ADVANTAGES OF VARIOUS POLICY APPROACHES

As policymakers weigh the options for fostering increased trailer efficiency, an overarching question is whether trailers will be subject to mandatory regulation or if agencies will elect to continue to resort to voluntary measures. There are a number of approaches that could be taken, and each has relative advantages and disadvantages. The EPA SmartWay Transport Partnership has been a model voluntary program across North America and for other countries around the world. The nonregulatory approach centers on SmartWay's ongoing work to improve the verification protocols to move from design-based to performance-based fuel-saving benefits. Such a voluntary approach has the benefits of potential broader influence on the in-use trailer fleet and avoiding complex technical regulatory development work that could also necessitate a stakeholder outreach process related to small businesses in the trailer manufacturing industry.

On the other hand, more direct regulatory approaches can offer a number of relative advantages. Rules for trailer efficiency can offer greater certainty than voluntary approaches for technology investments and deployment and hence for quantifiable fuel savings and CO_2 reductions from all new trailers entering the fleet. Such regulatory schemes can also more closely link tractor developments with trailer developments to ensure that their real-world interactions are considered.

Ideally, tractors and trailers should be regulated together for efficiency improvements since the two components work in concert as a system. Particularly in the case of aerodynamic drag, technological advances and features for tractors and trailers affect one another. As such, any aerodynamic improvements for trailers must be compatible with those for tractors and vice versa. However, regulatory design complications arise from the fact that trailers are manufactured by different companies from tractors as well as market dynamics in which combinations of tractors and trailers are constantly interchanged. If policymakers opt to pursue a regulatory option for trailers, a critical regulatory issue is how to incorporate them into the heavy-duty program.

One option would be the creation of a stand-alone regulation for trailers. Trailers would be regulated separately from tractors, and there would not be a link between the two via flexible mechanisms such as credit trading. Another strategy would be to integrate trailers into the existing heavy-duty vehicle program. In this option, trailers would, in effect, enter the heavy-vehicle program as a fourth equipment group, joining the existing three categories: tractors, vocational vehicles (such as dump trucks or garbage trucks), and heavy-duty pickup trucks and vans. Either of these options would entail new regulations for trailer manufacturers. Both could allow for a higher level of test procedure and certification integration between tractors and trailers, but extensive provisions would have to be developed to ensure that tractor and trailer technology compatibility issues were addressed. (This will be discussed in more detail in Section 5.2.) Both could allow the possibility of offering credits for "early action" before any Phase 2 regulatory provisions were formally implemented.

Stand-alone regulation has in its favor the sending of a clear and direct technology-forcing signal to trailer manufacturers and users. By creating testing and verification protocols, with threshold requirements for trailers' overall performance, the standards would be designed to ensure that cost-effective trailer aerodynamic, tire, and mass reduction technologies were installed on trailers through a prescribed phase-in period. This in turn provides the greatest certainty about trailer technology investment, deployment, and associated GHG and fuel use reductions.

Integrating trailers into the existing regulatory framework for heavy-duty vehicles—specifically, the tractor program—would be advantageous because it would allow for complementarity of test procedures and certification between tractors and trailers. The ability to link trailers to the averaging, banking, and trading (ABT) program of fuel consumption credits could provide an added element of flexibility (that is, additional opportunities for credit trading) for both tractor and trailer manufacturers. In devising a credit generation scheme for trailers, as is the case with the vehicle program, credits should be based on tons of carbon dioxide averted (or gallons of fuel spared) and based on anticipated savings over the life of the trailer. The credit calculation must acknowledge that there are roughly three times as many trailers in the fleet as tractors.

In addition to these two regulatory strategies, a voluntary opt-in crediting scheme for trailers could borrow structural elements from regulatory provisions for heavy-duty and light-duty vehicles. In this case the trailer manufacturer or technology supplier would have an incentive to test new devices within established protocols, and each associated fuel-saving technology certified would thus have a tangible fuel savings and emission reduction credit associated with it. The credits could then be sold to vehicle manufacturers and utilized as is any other credit within the ABT program to add flexibility for technologies that would otherwise not be advanced through the regulations for tractors. This voluntary opt-in crediting system is conceptually analogous to the light-duty vehicle “off-cycle” crediting provisions, whereby select technologies (active aerodynamics, stop-start, efficient accessories, etc.) that are not part of current test procedures are deployed receive credit toward compliance. In this scheme, manufacturers can supply data in exchange for various credit values and have a per vehicle maximum for allowable credits from all the off-cycle technologies. They can also choose not to deploy any of the off-cycle technologies and receive no credits.

If such voluntary crediting is pursued, there is a risk that the additional credits could compromise the integrity of the tractor regulation. One strategy for mitigating this risk is to devise provisions similar to those in the light-duty vehicle program in which off-cycle credits are capped at a certain level. In that case, heavy-duty vehicle manufacturers could only utilize a certain amount of trailer-generated credits toward compliance.

The principal advantages and disadvantages of the basic policy approaches are summarized in Table 5-1. The policy options are not necessarily mutually exclusive since the voluntary SmartWay approach for trailers could coexist with either regulatory option. One way to eliminate the challenge of creating a whole new class of regulated entities is found in the fourth option (“Regulatory trailer credits”), whereby original equipment manufacturers (OEMs) can obtain credits for aerodynamic trailers if the purchaser of trucks from the OEM signs a legally binding agreement to use these specially designed trailers. Such a program would be a logical extension of the arrangements between the OEMs and customers to accept speed limiters or automatic idling shutoff.

Table 5-1: General comparison of policy options to promote trailer efficiency

Policy option	Advantages	Disadvantages
Voluntary: Continuation of existing voluntary programs; no trailer regulation	• No additional regulatory development • Inclusion of in-use trailer fleet	• Uncertain technology adoption rates • Potential fuel and emission reductions limited by uncertain technology adoption
Stand-alone trailer regulation: New regulation with trailer manufacturers as regulated entities	• Test and simulation approach can link tractor and trailer interaction • Clear technology market signal • Highest potential fuel and emission reductions	• Additional regulatory development time • Risk of smaller trailer manufacturers being exempted from regulatory program • Only affects new trailers
Trailers integrated into the vehicle regulation: Trailers integrated into the existing vehicle program as another regulatory subcategory. Trailer manufacturers as regulated entities	• Same as the stand-alone option, plus: • Added compliance flexibility • Added compliance cost-effectiveness	• Additional regulatory development time • Assumption-dependent credit calculations • Only affects new trailers
Regulatory trailer credits: Trailers integrated into vehicle performance standards, but trailer OEMs are *not* directly regulated. Instead, a new compliance mechanism allows vehicle OEMs to obtain compliance credits based on legally binding commitments from tractor customers to purchase and use improved trailers	• Integration into vehicle existing compliance crediting schemes • Test and simulation approach can link tractor and trailer interaction • Added compliance flexibility • Added compliance cost-effectiveness • Could include the in-use market	• Additional regulatory development time • Assumption-dependent credit calculations • Extends program beyond regulated parties

5.2 TRAILER TEST PROCEDURES ISSUES

There are several additional questions relating to policies to promote trailer technologies. To some extent these questions are interrelated with the higher-level question about what form any trailer policy approach will take. For instance, will the regulatory standards (or voluntary crediting provisions) for trailers be component or design based (like the existing SmartWay design) or instead move to a performance-based testing protocol? How will different trailer types be segmented? How will trailers be tested or certified What would be the appropriate metric for establishing targets or credits for trailers?

Experience from the Phase 1 heavy-duty vehicle program can certainly inform the decision as to how trailers can be segmented and what types of trailer equipment would be the primary regulatory focus. In the Phase 1 heavy-duty vehicle program, Class 7 and 8 tractors are subject to standards that require improvements from multiple vehicle systems, while vocational vehicle standards are limited to the engine and tires. Finer segmentation of the diverse vocational vehicle subindustry is challenging and could lead to regulating the hundreds of body-builder and up-fitting companies that exist in the vocational space. Another reason that the EPA and NHTSA focused their regulatory stringency on the large tractor and heavy pickup truck classes in the Phase 1 vehicle program is that those two vehicle segments account for roughly 80 percent of the fuel used by the heavy-duty vehicle sector (U.S. Environmental Protection Agency 2011).

There are some salient parallels between the heavy-duty vehicle and trailer markets that can provide insights on potential strategies for structuring trailer regulation. As with vocational vehicles, there is a great deal of diversity in the non–box van trailer market. Another similarity to vocational vehicles is that non–box trailers account for much less of total trailer volume and activity, making up roughly 30 percent of the sales market as well.

Because of the correspondence with the heavy-duty vehicle market, some options for trailer regulation are based on the segmentation strategy employed in the Phase 1 vehicle program. As discussed in Chapter 2, the three primary areas for reducing road-load resistance from trailers are rolling resistance, aerodynamics, and lightening the vehicle weight. With the growing availability of low rolling resistance tire models for trailers, there is no technical barrier to creating a rolling resistance standard, or component-based specifications or crediting provisions within that standard, for all types of trailers. The EPA and NHTSA considered a case in which trailers were regulated for tire rolling resistance (U.S. Environmental Protection Agency 2011). A program in which all trailer types are subject to improved tire rolling resistance would be similar to the Phase 1 heavy-duty vehicle regulation in which tire rolling resistance improvements were included in the setting of the stringency levels for all vehicles covered in the rule.

However, integrating trailer aerodynamic and weight reduction improvements into regulatory provisions would be more complex than for tires. Two distinct strategies for integrating aerodynamic and bulk-lightening provisions into a regulation are summarized in Table 5-2. In the first option, the entire market is divided into box (dry and refrigerated) trailers and non–box trailers. Regulatory requirements for box trailers would be set based on improvements in both rolling resistance and aerodynamics, and use of lightweight materials could be credited as well. For non–box trailers, there might only be tire rolling resistance provisions. With any performance-based standard, improvements are measured versus a baseline, and perhaps the biggest advantage of this type of approach is that it would avoid the arduous task of developing comprehensive baseline aerodynamic data for the multitude of trailer types and configurations that fall into the non–box category. In contrast, it would be much more straightforward to determine baseline aerodynamic performance for box vans, given the wealth of testing data readily available in the literature and through the SmartWay program. However, in setting the baseline for box vans, an important issue to consider is the degree of uptake of trailer aerodynamic devices that has already occurred because of general customer adoption as well as the California Heavy-Duty (Tractor-Trailer) Greenhouse Gas Regulation.

One potential downside if non–box trailers are not subject to regulatory requirements based on aerodynamic streamlining and weight reduction is that non–box trailer manufacturers may have very little incentive to invest in such improvements. Underbody devices like aerodynamic skirts have been touted by suppliers as providing benefits for non–box trailers such as tankers and flatbeds (Freight Wing n.d.; Load Covering Solutions n.d.), and these could be included in the regulatory requirements for all trailer types. It appears that much more independent testing and research is needed for non–box trailer aerodynamic devices beyond underbody devices. If the federal agencies elect to regulate only box trailers, they could incentivize additional aerodynamic improvements in non–box trailers by allowing these manufacturers to generate "innovative technology" credits that could be used in an ABT program.

A second strategy would make all trailer types subject to "full equipment" standards. Owing to the significant diversity of the non–box trailer market, this approach would require a fair amount of binning based on physical trailer characteristics. Though this method of segmentation would take much more effort than the two-category (box and non–box trailer) approach, the trailer market data in Chapter 3 indicate that there are distinct categories that represent large fractions of the market. Similar to what was done for the Phase 1 vehicle standards, the agencies would have to develop regulatory subcategories based on physical characteristics and work with the trailer industry to create a system of bins that reasonably segment the trailer market.

Table 5-2: Advantages and disadvantages of "full-equipment" standards for non–box trailers

Policy option	Advantages	Disadvantages
Two-category: Full equipment requirements for box van only; tire and aerodynamic skirt requirements only for non–box trailers	• Developing aerodynamic baseline is much more straightforward for box-van trailers • Tire, aerodynamic, and weight reduction requirements for only box-van trailer types avoids major complexities for diverse non–box trailers • Additional technologies, devices, and mass reduction technologies can routinely be incorporated via "innovative technology" credits	• Complexity in development of rigorous data-driven accounting for improvements for all aerodynamic devices, for differing trailer types, for differing tractor-trailer interactions
Full equipment: Aerodynamic and tire requirements for all trailers	• Trailers could be binned by physical characteristics, which is similar to the approach taken for Class 7 and 8 tractors in the Phase 1 vehicle regulation	• Difficulty in developing aerodynamic baselines for many non-box-van trailer types • Additional program complexity may not translate to substantial GHG and fuel savings beyond the above option

Full equipment includes aerodynamic, tire rolling resistance, and credit for mass reduction

Testing and certification will be critical in establishing regulatory provisions that involve trailers. It will be highly advantageous for the regulatory agencies to align the certification methods for tractors and trailers as closely as possible, to ensure that tractor-trailers that operate as a system in real-world driving conditions use a test regime that most closely simulates this reality.

As with tractors, the rolling resistance coefficient values (C_{RR}) for trailer tires can be determined using the International Organization for Standardization test method 28580:2009 (International Organization for Standardization 2009), which tests tires in a laboratory on a machine drum. Unlike rolling resistance testing, determining aerodynamic characteristics is much more complicated. In the Phase 1 vehicle program, to determine the aerodynamic coefficient of drag (C_d), tractor manufacturers may use coast-down testing (a modified SAE J1263 procedure[17] that is referred to in the rule as the "enhanced coastdown procedure"), wind tunnel testing, or computational fluid dynamics (CFD) simulation. However, to address consistency concerns, the enhanced coast-down method has been set as the reference test method, and, as such, all C_d results developed using wind tunnel testing or CFD must be aligned with the reference method.

There are challenges that are inherent to performing coast-downs on a test track, such as variation in temperature, humidity, track surface conditions, and ambient wind speed. In addition, as evidenced in the testing done by Hausberger, Rexeis, Blassnegger, and Silberholz (2011), the specific tractor that is paired to a trailer can affect the determination of the aerodynamic coefficient of drag. To mitigate the inherent uncertainty in using absolute values of C_d from track testing results, the EPA and NHTSA devised a binning strategy for the Phase 1 tractor program. In this approach, values for C_d from track tests multiplied by the vehicle's frontal area are grouped into five bins, or subcategories, and each of these is assigned a default C_d value that is used in the Greenhouse Gas Emissions Model (GEM)[18] simulation to determine the certified CO_2 or fuel consumption level.

If the EPA and NHTSA wish to align the test methods for tractors and trailers, they can use coast-down testing as a reference method and employ a similar binning approach for trailers. The number of subcategories could be based on the current aerodynamic reduction levels in the SmartWay program for trailers—that is, 1 percent, 4 percent, and 5 percent—or a new binning system could be devised.

Once the test method is determined for trailers, the agencies must devise a strategy for translating test values into certification values that are needed for assessing compliance. Maintaining congruence with the tractor program would entail integrating trailers into the GEM simulation tool, which seems relatively straightforward.

In terms of testing and certification procedures, the trailer cannot be isolated totally from the truck in any analysis. It is important to define trailer drag in some consistent fashion: consider that the trailer drag is the sum of the axial forces at the tractor fifth wheel and at the rear suspension. The truck dictates the upstream conditions and sets the airflow field that encounters the trailer. Trucks with substantially distinct aerodynamic designs or with varying gap separation from the trailer will affect the drag on the trailer differently while operating at steady speed. They may also affect the benefit conferred by trailer aerodynamic devices. Second, it is important to note that some drag reduction devices, such as truck rooftop fairings, could, in theory, equally well be attached to the trailer. However, trucks have received greater attention because they are outnumbered substantially by trailers. Also, geometric constraints favor attachment of devices to the truck, and some aerodynamic devices offer additional headroom in sleeper cabs. Third, it is not clear whether the truck or the trailer is responsible for the losses associated with the gap, but the consistent definition of

17 See Section 3.2.2.1 of the EPA's Regulatory Impact Analysis for more information about the Society of Automotive Engineers (SAE) 1263 test procedure and the modifications that have been adopted for this rulemaking. The most notable modification in the test procedure is that low- and mid-roof tractors will be tested in a bobtail (i.e., no trailer) configuration.

18 For the Phase 1 vehicle program, the EPA and NHTSA have developed a MATLAB/Simulink-based software program called the Greenhouse Gas Emissions Model (GEM) to evaluate fuel use and CO_2 emissions through the simulation of whole-vehicle operation. This model is used to certify vehicle compliance with GHG and fuel efficiency standards, based on model inputs specific to each vehicle.

trailer drag presented earlier in this paragraph can render this consideration redundant. The presence of the trailer, even when the drawbar pull is subtracted, will affect the truck's own drag force. All of these issues must be taken into consideration when designing test protocols that measure tractor-trailer performance.

In addition, in order to certify trailers for fuel efficiency performance, it is essential that the EPA and NHTSA develop a robust certification procedure for the safety and durability of all equipment covered in any future policy measure focusing on trailers.

6 CONCLUSIONS AND RECOMMENDATIONS

In North America and in many other places in the world, tractor-trailers represent the majority of fuel use and emissions from the on-road freight transportation sector. From a technological perspective, there are numerous areas where improvements can be made to tractor-trailers to boost their efficiency. Table 6-1 lists the major technologies that are commercially available or emerging to reduce the GHG emissions and fuel consumption of tractor-trailers. Advances in engine design, low rolling resistance tires, streamlined aerodynamics, and idling reduction technologies are all being directly promoted within the U.S. heavy-duty Phase 1 regulations for tractors; as a result, these are being adopted for new tractors in increasing numbers.

As for trailers, technological interventions for increasing efficiency generally fall into three categories: improved aerodynamics, reduced rolling resistance, and lower curb weight. In recent years, there have been many engineering refinements and product development targeted on improving airflow around trailers. Trailer technologies have been deployed to reduce aerodynamic drag in three main areas: the tractor-trailer gap, the side and underbody of the trailer, and the rear of the trailer. Also, tire technologies continue to progress, and there are many trailer tire models (dual tire sets and single-wide tires) that offer low rolling resistance and thus contribute directly to fuel savings. In addition, tire inflation processes are better able to maintain optimum tire pressure, improving fuel efficiency and tire life. Finally, alternative materials such as composites and aluminum can be used in trailer wheels as well as in the structure of the trailer itself in order to decrease its empty weight, which leads to reduced rolling resistance and inertial drag.

Table 6-1: Tractor-trailer technologies

Area	Technology	Potential fuel consumption reduction
Engine	Engine friction and parasitic load reduction (piston; water, fuel, oil pumps)	0.5 – 1.5%
	Advanced controls, combustion, fuel injection improvements (fuel rail, injector, cylinder head, EGR improvements)	0.5 – 2.5%
	After-treatment improvement	0.5 – 1.5%
	Turborcharging efficiency and air handling improvements	1.0 – 1.8%
	Turbo-compounding with clutch	2.5 – 5.0%
Transmission	Appropriate gear/ratio specs	1 – 3%
	Friction reduction	1 – 1.5%
	Direct drive	1.5 – 2%
	Single drive axle	1%
	Automated manual	4 – 8%
	Automatic transmission	0 – 5%
Tractor	Aerodynamics—Day cab roof deflector	3 – 5%
	Aerodynamics—Sleeper roof fairing	3 – 5%
	Aerodynamics—Chassis skirt	3 – 4%
	Aerodynamics—Cab extender	2 – 3%
	Low rolling resistance steer/drive tires	1 – 3%
	Weight reduction—aluminum, single wide	0 – 1%
	Auxiliary power unit	5 – 6%
Trailer	Aerodynamics—Partial skirts (4–6 m)	3 – 4%
	Aerodynamics—Full skirts (7–9 m)	4 – 6%
	Aerodynamics—Partial gap reducer (cuts gap ~ in half)	1 – 2%
	Aerodynamics—Full gap reducer (fully closes gap)	2 – 3%
	Aerodynamics—Boat tails	4 – 6%
	Low rolling resistance tires	1 – 2%
	Improved wide-base single tires + aluminum wheels	4 – 6%
	Partial aerodynamic package	4 – 8%
	Full aerodynamic package	7 – 11%

Based on Kromer, Bockholt, and Jackson, 2009; Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles, 2010; U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, 2011

Despite a number of trailer technology options that have been shown to provide real-world fuel savings, it is unclear exactly what the adoption rate is for many of them. More detailed sales data are needed to assess the state of technology deployment in the trailer market.

Ongoing ICCT research is investigating the various barriers that are impeding technology deployment for tractor-trailers. Perhaps at the forefront of these barriers is the uncertainty of end users about the potential fuel savings that a given technology can provide for their particular mission. Third-party, unbiased assessment of technology efficacy may be difficult to obtain, and it can often be an expensive proposition for fleets to conduct their own testing or pilot programs. Programs such as the U.S. Environmental Protection Agency (EPA) SmartWay Transport Partnership are working to reduce this uncertainty by testing and validating technologies and providing a repository wherein industry can find data and information about technology performance. Other barriers are financial in nature, such as capital constraints, short payback time requirements, or warranty issues, as well as the inconvenience that a technology might pose in terms of disrupted operations or additional maintenance requirements. In addition, size and weight restrictions can throw up barriers to technology adoption.

As with heavy-duty vehicles, the trailer market is diverse, and there are myriad sizes and configurations to cover a wide range of freight operations. Despite this great diversity, box-type dry and refrigerated vans represent roughly two-thirds of the sales market and likely account for a large percentage of total trailer miles traveled. In terms of manufacturing and sales, the trailer market is fairly consolidated, with the largest five companies accounting for about two-thirds of sales. The van trailer marker is even more consolidated, with the top five companies representing more than 90 percent of the market.

To date, policies directed toward trailer efficiency improvements have generally been voluntary. Since its inception, the SmartWay program has spurred a number of initiatives focused on verifying trailer technology performance and disseminating information and test data free of charge to fleet users and the general public. Building on the success of the SmartWay program, California's Air Resources Board crafted a mandatory regulation for both tractors and trailers operating in that state that is being phased in through 2020. For trailers, the rule includes provisions for both aerodynamic and rolling resistance improvements.

In the federal government's finalized regulation for medium- and heavy-duty vehicles, the EPA and the National Highway Traffic Safety Administration acknowledged that there are substantial fuel savings to be achieved by regulating trailers; however, the agencies said that they did not include trailers in the initial Phase 1 heavy-duty vehicle regulation primary because of time constraints and the need to have a intensive consultation with the trailer industry, which has never been regulated in terms of fuel efficiency or GHG emissions. However, as indicated by Table 6-1, continuing to omit trailers from the overall heavy-duty vehicle program amounts to forgoing a substantial opportunity to support an entire group of technologies available to increase tractor-trailer efficiency.

As policymakers weigh options for promoting trailer technology with new policies for heavy-duty vehicles, this assessment's findings point to the following recommendations:

1. **Integrate trailers into the Phase 2 U.S. heavy-duty vehicle regulatory program.** Bringing trailers into the broader regulatory program acknowledges that tractors and trailers by design operate as a system. Integrating trailers into the Phase 2 heavy-duty regulatory program could open up possibilities for flexibility in terms of

compliance if tractor and trailer original equipment manufacturers were allowed to trade credits.

2. **Create an opportunity for early deployment of trailer technology.** It is foreseeable that the second phase of the heavy-duty vehicle regulation will not begin until 2020 or so. Offering an opportunity for trailer technology innovation to be credited and acknowledged within the regulatory framework at an early stage encourages trailer industry technology leaders to adopt improvements well in advance. In addition, such early credit programs help the trailer industry to familiarize itself with the various aspects of the rule, including testing, compliance, crediting, and reporting.
3. **For aerodynamics and weight reduction, focus the regulatory requirements on box-type trailers but incentivize improvements for non–box trailers as well.** Box-type or van trailers represent the majority of fuel consumption, and, given the diversity of shapes and configurations in the non–van trailer market, it seems reasonable that the program—at least in the first phase of the regulation—should focus on van trailers in terms of aerodynamic and weight reduction improvements. To devise incentives for aerodynamic improvements for non–van trailers, “innovative technology” crediting based on coast-down testing or simulation modeling could be used in determining credit values. Underbody skirts seem to be the most universal of aerodynamic devices in terms of their simplicity and applicability across trailer types.
4. **For rolling resistance, establish regulatory requirements for all trailer types.** There are no apparent technical impediments to having rolling resistance standards extend to all trailer types. Policy action aimed at non–van trailers would be a good complement to California’s program, which only regulates dry- and refrigerated-van trailers.
5. **Use an equivalent test method and certification approach for tractors and trailers.** If coast-down testing remains the reference test method for determining aerodynamic characteristics in the Phase 2 tractor program, it is reasonable that trailers be subject to the same testing approach. Using absolute values for testing aerodynamic drag can be a difficult prospect due to reliability and repeatability issues (e.g., variable weather, track conditions, other location-specific characteristics, etc.). To overcome the uncertainty of track testing results, an aerodynamic binning approach was taken in the Phase 1 tractor program, and a similar approach could be applied to trailers. In addition, a module for trailer-specific inputs could supplement the GEM vehicle simulation program (to evaluate fuel use and CO_2 emissions through the simulation of whole-vehicle operation). The trailer program would also benefit from a crediting system that acknowledges mass reduction stemming from lightweight materials and design optimization, which diminishes the weight of trailers without compromising utility.

In addition to these recommendations, the federal agencies should be encouraged to continue to analyze the trailer market and reach out to the many stakeholders from industry, government, and the research community. Studies such as the National Academy of Sciences report from 2010 (cited in Chapter 2) provide an excellent foundation for trailer technology efficacy and cost estimates. Looking toward the 2020 time frame and beyond, this research should be refreshed. This updated analysis will allow policymakers to develop new estimates of the costs and benefits of any potential trailer regulation.

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APPENDIX A. ADDITIONAL TRAILER DATA

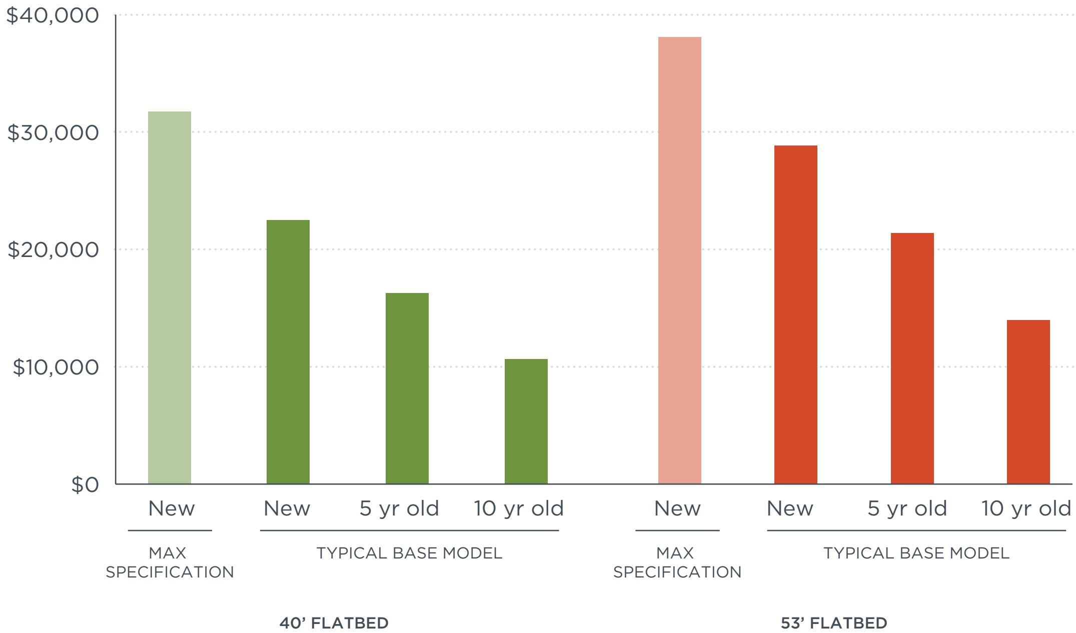

Figure A1: Typical Prices for New and Used Flatbed Trailers[19]
Based on data from (Price Digest 2012)

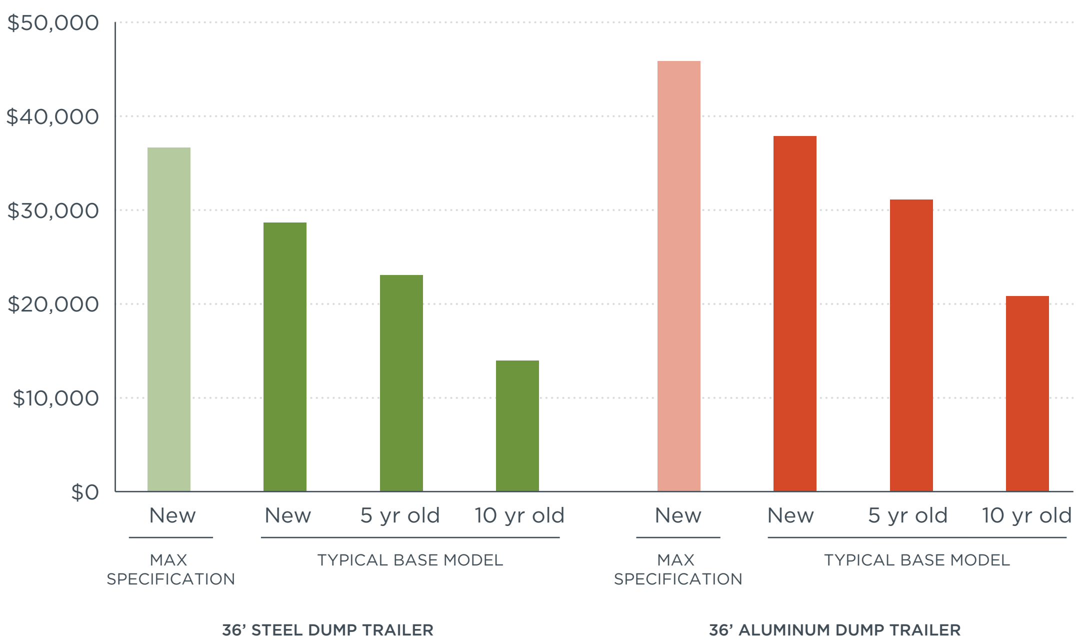

Figure A2: Typical Prices for New and Used Dump Trailers[20]
Based on data from (Price Digest 2012)

19 Costs shown are for aluminum flatbed trailers. A new 53-foot and 40-foot flatbed trailer typically cost approximately $29,000 and $22,000 respectively if they are constructed of steel.

20 Features in the max specification package include air ride suspension, two-way gate, heavy-duty and water-tight construction, and a roll-over canvas cover.

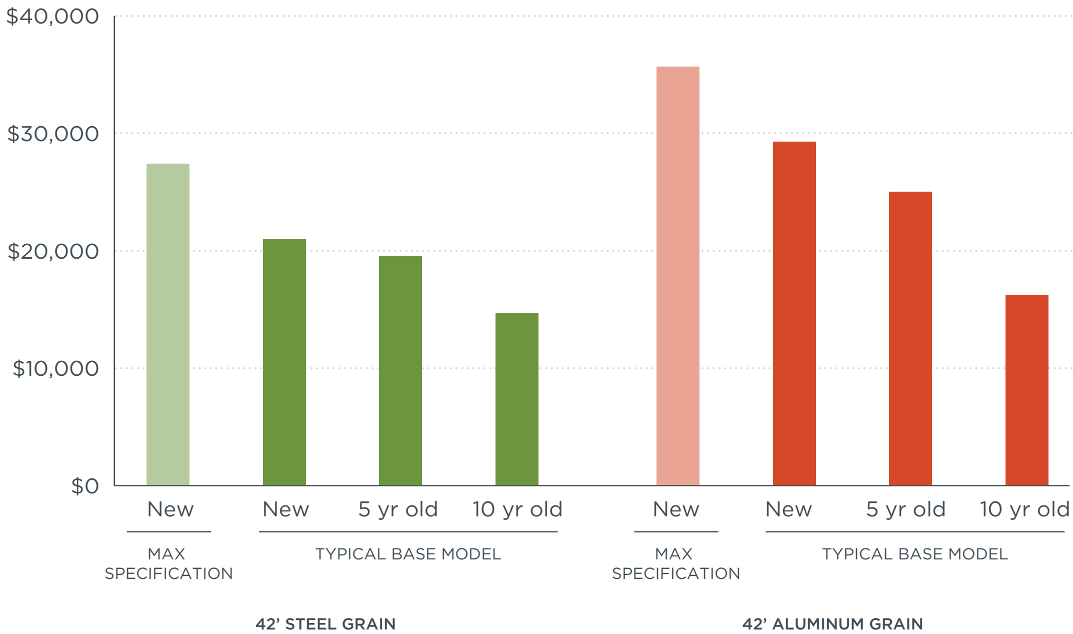

Figure A3: Typical Prices for New and Used Grain Trailers[21]
Based on data from (Price Digest 2012)

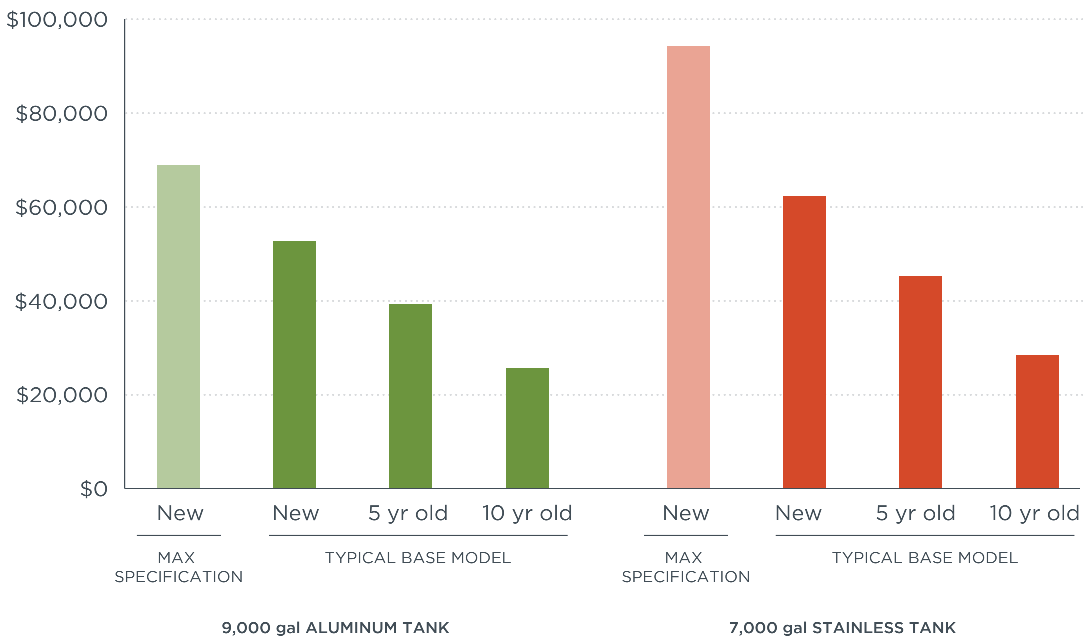

Figure A4: Typical Prices for New and Used Tank Trailers[22]
Based on data from (Price Digest 2012)

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21 Features in the max specification package include air ride suspension, 102" width, 72" sides, and multiple bins.

22 For the 9,000-gallon tanker, the max specification package includes air ride suspension, longer length, four or more insulated and heated compartments, certification for hauling hazardous materials (MC 407), manifold lines, and vapor recovery. For the 7,000-gallon tanker, max specification features include air ride suspension, five insulated compartments, certification for hauling liquefied petroleum gas or chlorine (MC331/431), on-board pump, and vapor recovery.

APPENDIX B. CURRENT U.S. EPA SMARTWAY VERIFIED PRODUCTS

Trailer Gap Reducers

Trailer Gap Reducer (should be used with side skirts) — estimated fuel savings: 1 percent or greater.

- Carrier Transicold Gap Fairing
- FreightWing Gap Reducer
- Laydon Composites Gap Reducer
- Nosecone "Nose 3-D" Gap Reducer (consists of top and side units sold as one piece of equipment)

Trailer Boat Tails

Trailer Boat Tail (this or the gap reducer should be used with side skirts) — estimated fuel savings: 1 percent or greater.

- Aerodynamic Trailer Systems (ATS) dual lobe boat tail
- AeroVolution inflatable boat tail
- ATS SmartTail
- Kodiak Innovations Bumper Bullet
- SOLUS Air Conqueror Package SP: 4.9 (WheelCover/AftSkirt/Tail1)
- SOLUS Air Conqueror Package SP: 3.6 (WheelCover/AftSkirt/Tail2)
- SOLUS Air Conqueror Package SP: 3.4 (WheelCover/AftSkirt/Tail3)
- SOLUS Air Conqueror Package SP: 2.4 (WheelCover/AftSkirt)
- Transtex rear trailer fairing

Trailer Side Skirts

Trailer Side Skirts (should be used with gap reducer or boat tail) — estimated fuel savings: 4 percent or greater.

- Carrier Transicold Belly Fairing
- Fleet Engineers Extended Air Slipper
- FreightWing belly fairing Trailer Skirts
- Kodiak Innovations AirPlow
- Laydon Composites Trailer Skirts 6 or 7 panel
- Ridge Corp. GreenWing RAC0002
- Silver Eagle Mid-length Skirt
- Silver Eagle Mini-skirt
- SOLUS Air Conqueror Split Skirt SSR I (12-0-6)
- SOLUS Air Conqueror Split Skirt SSR II (12-2-6)
- SOLUS Air Conqueror Split Skirt SSA I (12-4-6)
- SOLUS Air Conqueror Split Skirt SSA II (14-2-6)
- Transtex Trailer Skirts
- Utility Trailer Utility Side Skirt 120

Advanced Trailer End Fairing

Advanced Trailer End Fairing (this can be used with or without other fairings) — estimated fuel savings : 5 percent.

- ATDynamics TrailerTail rear trailer fairing
- ATDynamics TrailerTail Trident
- ATS Integrated Automated System (WindTamer with SmartTail)
- Avantechs Inc VorBlade Wing (with Crosswinds Mitigator subsystem)
- SmartTruck UT-1
- SmartTruck UT-6

Advanced Trailer Skirt

Advanced Trailer Skirt (this can be used with or without other fairings) — estimated fuel savings: 5 percent.

- Aerofficient Aero-slide side fairing system (with rearmost telescoping panel) (model ASFS)
- Aerofficient Fixed side fairing (with landing gear wrap panel) (model FFGW)
- Aerofficient Fixed side fairing (with landing gear toe in panel) (model FFTI)
- Airflow Deflector Deflector
- American Trailer Skirts American Trailer Kit
- ATDynamics-Transtex Trailer Side Skirts
- Atlantic Great Dane AeroGuard Side Skirt (AGD400-43)
- Brean Marketing, Inc. ArrowShield
- Carrier Transicold Aeroflex Fairing
- FreightWing Aeroflex Trailer Skirt
- Kodiak Innovations AeroCurtain
- Laydon Composites Trailer Skirt 8 panel
- Laydon Composite Classic 7-Panel Trailer Skirt, Product code TRSK700SA
- Laydon Composites Curve
- Laydon Composites Hybrid 248 (Intermodal) Trailer Skirt
- Laydon Composite Hybrid 259 Trailer Skirt, Product code TRSK710SA
- Ridge Corp. GreenWing RAC0003
- Ridge Corp. GreenWing RAC0012
- Silver Eagle Aero Saber
- SOLUS Air Conqueror Performance Split Skirt SSP I (14-0-6)
- SOLUS Air Conqueror Performance Split Skirt SSP II (16-0-6)
- SOLUS Air Conqueror Performance Split Skirt SSP III (18-0-6)
- Strehl Model 715
- Sweet Bottom Trailer Skirt
- Transfoil Systems Transfoil

- Transtex MFS Trailer Side Skirts
- Utility Trailer Utility Side Skirt 120A
- Utility Trailer Utility Side Skirt 160
- Wabash National Advanced Trailer Side Skirt, DuraPlate AeroSkirt — Standard
- Wabash National Advanced Trailer Side Skirt, DuraPlate AeroSkirt — Angled
- Windyne Flex-Fairing

Low Rolling Resistance Tires for Trailers

- Aeolus HN808
- Arisun CR915
- BF Goodrich TR144
- Bridgestone Greatec R135
- Bridgestone Ecopia R195
- Bridgestone Ecopia R197
- Bridgestone Ecopia S197
- Continental HTL ECO Plus
- Continental HTL1
- Double Coin FT105
- Double Coin FT125
- Dunlop SP193 FM
- Falken RI119 Ecorun
- Firestone FT455 PLUS
- General ST250
- Goodride CR915
- Goodyear G316 LHT Fuel Max
- Goodyear G316 LHT Fuel Max Duraseal
- Goodyear G394SST
- Hankook TL 01
- Kumho KLT02e
- Leao ATE821
- Michelin XTA Energy
- Michelin XT1
- Michelin X-One XTA
- Michelin X-One XTE
- Roadmaster (Cooper) RM871
- Roadpro R910FS
- Sumitomo Trailer ST710SE
- Toyo Tires Trailer M157

- Westlake CR915
- Yokohama RY407
- Yokohama RY587
- Yokohama RY587mc2

Low Rolling Resistance Retread Technologies for Trailers

- Bridgestone/Bandag B197 FuelTech (precure)
- Continental HTL Eco Plus (precure)
- Michelin XT1-AT (precure)