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Recommendations for Regulatory Design, Testing, and Certification for Integrating Trailers into the Phase 2 U.S. Heavy-Duty Vehicle Fuel Efficiency and Greenhouse Gas Regulation

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EXECUTIVE SUMMARY

This paper summarizes recent ICCT research on the integration of trailers into Phase 2 of the U.S. regulations covering heavy-duty vehicle fuel efficiency and greenhouse gas (GHG) emissions. In the final Phase 1 regulation for heavy-duty vehicles, the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) acknowledged that there are substantial, cost-effective fuel savings and GHG emission reductions to be achieved by regulating trailers. However, the agencies omitted trailers from the initial Phase 1 heavy-duty vehicle regulation primarily because of time constraints and the need for an intensive exchange with the trailer industry, which has never been regulated in terms of fuel efficiency or GHG emissions. Including trailers in the overall heavy-duty vehicle program will promote an entire group of available aerodynamic, tire rolling resistance, and lightweighting technologies to increase tractor-trailer efficiency.

This paper focuses on the specific ways in which trailers can be incorporated into the regulation. The guiding principle in this analysis is that the classification framework, as well as the testing and certification procedures, for trailers should be as closely aligned to that of tractors as possible. As policymakers in the U.S. and Canada 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 would greatly increase the fuel and GHG reductions of the program from cost-effective off-the-shelf technologies. The approximate potential benefits from trailers are approximately 7–10% per tractor-trailer, as compared with the 17–23% per tractor from the Phase 1 program that excludes trailers.

2. **Make trailer manufacturers a directly regulated entity within the overall heavy-duty vehicle regulatory program.** Regulating trailers primarily as a separate regulated entity, instead of a more directly integrated way within the tractor regulation or via credits, has two key advantages. First, there is increased certainty that fuel-saving trailer technologies will be adopted, and second, this framework provides regulatory clarity for both tractor and trailer manufacturers.

3. **Develop a trailer classification framework that facilitates improvements in aerodynamics, tire rolling resistance, and lightweighting in box trailers as well as improvements in tire rolling resistance for all trailer types.** Regulating box trailers for all three technology areas—aerodynamics, tire rolling resistance, and lightweighting—will yield the majority of benefits from a trailer program. Tire rolling resistance standards can be introduced for all trailer types, and aerodynamic and weight reduction improvements in non-box trailers can be incentivized through a crediting scheme. As with the Phase 1 regulation, policymakers should create a simple classification structure for trailers that is easily understood and avoids the complex task of creating regulatory subcategories within the non-box trailer category.

4. **Build on the success and experience of the Phase 1 regulation and align the testing and certification procedures for tractors and trailers as much as possible.** Assuming coastdown testing continues as the reference test method for tractors in the Phase 2 regulation, this test method should be used for trailers as well. Wind tunnel and CFD testing can also be allowed for trailers, provided that these results are normalized against coastdown test results. In addition, the optional provision in

the Phase 1 regulation for testing tractors in crosswind conditions should be made available for trailers as well. Finally, similar to the Phase 1 approach for tractors, an aerodynamic binning approach should be used for trailers. This scheme assigns default coefficient of drag (C_D) values for each aerodynamic bin and avoids manufacturers having to input test results from coastdown testing (or wind tunnel or CFD testing) directly into the Greenhouse Gas Emission Model (GEM) simulation tool. As with tractors, the GEM simulation program should be used for trailers for final certification.

5. **For trailer aerodynamic testing, pursue an “A-to-B” approach in which an identical tractor is used to test both a baseline and an “enhanced” trailer in order to certify the enhanced trailer model’s aerodynamic bin level.** The tractor used during trailer aerodynamic testing can have significant effects on the coefficient of drag. To avoid the arduous task of creating detailed specifications for a “standard tractor,” the agencies should base aerodynamic certification on an “A-to-B” testing approach, where a trailer manufacturer uses a particular tractor to test both their baseline (i.e., no aerodynamic improvements) and an enhanced aerodynamic trailer.

6. **Utilize a grams/ton-mile (and functionally equivalent gallons/ton-mile) certification metric for trailers that is identical to the metric used for tractors and vocational vehicles in the Phase 1 regulation.** For maximum harmonization across the overall heavy-duty GHG regulation, the grams/ton-mile metric should be used for trailers. For the averaging, banking, and trading (ABT) program, credits and debits should be in tons (or gallons), as with the other vehicle categories.

These recommendations point toward a Phase 2 heavy-duty vehicle regulatory program for the U.S. and Canada that more comprehensively promotes known cost-effective technologies for tractor-trailers. We have seen the success of the early voluntary efforts from the U.S. EPA’s SmartWay program as well as the California tractor-trailer GHG regulation drive trailer technology development, technology cost reductions, and increasing adoption of trailer technology. The regulatory approach recommended in this paper would offer a natural extension of the same policy principles, but with wider fleet fuel savings and carbon emission benefits.

1 INTRODUCTION

In North America and many places in the world, tractor-trailers represent the majority of fuel use and greenhouse gas (GHG) emissions from the on-road freight transportation sector (Facanha, Blumberg et al., 2012). From a technological perspective, there are a multitude of areas where improvements can be made to tractor-trailers to greatly increase their efficiency. Specific to trailers, technological interventions for increasing efficiency generally fall into three categories: improved aerodynamics, reduced rolling resistance, and lowered curb weight.

In the final rulemaking for medium- and heavy-duty vehicles (HDVs), the EPA and NHTSA acknowledge 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 HDV regulation, primarily because of time constraints and the need for a intensive exchange with the trailer industry, which has never been regulated in terms of fuel efficiency or GHG emissions (U.S. EPA, 2011). However, as the agencies are in the process of developing the Phase 2 regulation, continuing to omit trailers from the overall HDV program amounts to forgoing a substantial opportunity to promote an entire group of available technologies to increase tractor-trailer efficiency.

The fundamental starting point for this paper is that trailers will be integrated into the Phase 2 fuel efficiency and GHG regulation for heavy-duty vehicles in some manner. This paper therefore builds upon the assessment of the previous work that considered various options for bringing trailers into the regulatory program (see Sharpe et al, 2013). That piece discussed the advantages and disadvantages of several approaches to promote known cost-effective trailer technologies in the tractor-trailer fleet. Based on the previous work, Table 1 summarizes these pros and cons of various options to promote trailer efficiency technology. The policy options are not necessarily mutually exclusive, as the existing voluntary SmartWay program could certainly complement any of the regulatory options and continue to be a model public-private partnership program for promoting freight efficiency across North America and other countries and regions around the world.

Integrating trailers into the overall heavy-duty program as a separate regulated entity has the clear advantages of promoting trailer technology across the fleet and allows for a high level of test procedure and certification integration between tractors and trailers. This recommended approach is shown in Table 1 as the third option. Another key advantage of this approach is the ability to link trailers and tractors via the ABT program, which could potentially provide an added element of flexibility (i.e., additional opportunities for credit trading) for both tractor and trailer manufacturers. The disadvantages of trailers as a direct regulated entity can be largely sidestepped or mitigated with the regulatory framework described in Section 2.

Table 1: 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 • Uncertain fuel-saving 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	• No opportunity for credit trading within the broader HDV regulation • 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	• Assumption-dependent credit calculations • Only affects new trailers
Regulatory trailer credits: Trailer OEMs are *not* directly regulated. 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 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	• Assumption-dependent credit calculations • Complication of extending program beyond regulated parties

In this paper's recommended approach, new trailers will be an additional regulated equipment category, just as tractors, heavy-duty pickup trucks and vans, and vocational vehicles are the three primary vehicle categories in the Phase 1 regulation. The primary purpose of this paper is to offer a discussion piece for policymakers on the question of how best to integrate trailers into the existing test procedure and certification framework for tractors and leverage the experiences of the Phase 1 regulatory development process. This paper is narrowly focused on strategies for testing and certifying trailers in the context of a regulatory program for fuel consumption and GHG emissions. Its scope is intentionally limited; for a broader analysis of trailer technologies, market conditions, and policy considerations, interested readers can reference this paper's companion ICCT report (Sharpe, Clark et al., 2013).

The paper begins by presenting a proposed framework for trailer classification. The two subsequent sections outline some of the key issues involved with trailer aerodynamic testing and certification. Following the discussion of aerodynamic certification, the paper presents some guiding principles, based on elements of the Phase 1 rule for tractors, for integrating tire rolling resistance and weight reduction into the trailer regulation. The final section of the paper discusses the reasons why the metric for certification, as well as the credit/debit unit for the ABT program for trailers, should be identical to those used in the overall heavy-duty vehicle regulation.

2 TRAILER REGULATION DESIGN CONSIDERATIONS

2.1 TRAILER CLASSIFICATION

There are some salient parallels between the heavy-duty vehicle and trailer markets that can provide insights into potential strategies for organizing trailers into regulatory sub-categories. In the Phase 1 regulation, heavy-duty vehicles were grouped into three broad regulatory categories: Class 7 and 8 tractors, heavy-duty pickup trucks and vans, and "vocational vehicles," which are a catch-all category for all on-road HDVs that are not defined as either of the other two. As with the expansive vocational vehicle category, there is a great deal of diversity of equipment types in the non-box trailer market (e.g., tanker, flatbed, grain, dump, etc.). Another similarity to the vocational vehicle segment is that non-box trailers account for much less of the total trailer market, making up roughly 30 percent of the sales, while box trailers (dry and refrigerated trailers) represent nearly 70% of the sales market. Though more research is needed to determine a more precise breakdown of miles traveled among the various trailer types within the fleet, it seems reasonable to assume that based on the trailer sales data and anecdotal evidence from North America's largest trucking fleets, box trailers represent the large majority of tractor-trailers miles, fuel consumption, and GHGs as compared with non-box trailers.

Due to these similarities with the HDV market, it may be advantageous for trailer classification to be based on a similar segmentation strategy that is employed in the Phase 1 vehicle regulation. In a classification approach for trailers that mirrors the strategy of creating a catch-all category for vocational vehicles, the agencies could create a non-box trailer category, which would include all of the many types of trailers such as tankers, flatbed, grain, and dump trailers that are not dry or refrigerated box (or "van") trailers.

With the growing availability of low rolling resistance tire models for trailers, there do not seem to be technical barriers to creating a rolling resistance standard for all types of trailers, including non-box trailers. A program in which all trailer types are subject to improved tire rolling resistance would be similar to the Phase 1 HDV regulation, in which tire rolling resistance improvements were included in the setting of stringency levels for all vehicles covered in the rule.

However, integrating trailer aerodynamic and weight reduction improvements into regulatory provisions for non-box trailers would be much more complex than for tires. By only setting tire rolling resistance requirements for non-box trailers, the agencies can avoid the arduous task of developing comprehensive baseline aerodynamic and weight data for the multitude of trailer types and configurations that fall into the non-box category. If the EPA and NHTSA elect only to mandate tire improvements for non-box trailers, the agencies can incentivize advances in aerodynamics and lightweighting by allowing non-box trailer manufacturers to generate "innovative technology" credits that could be used in an ABT program.

In contrast to non-box trailers, it would be much more straightforward to determine baseline aerodynamic and curb weight characteristics for box trailers, given the wealth of testing data readily available in the literature and through the SmartWay program. Aerodynamic testing and certification for box trailers is discussed in detail in the following section.

Box trailers include both dry and refrigerated trailers ("reefers"), and there are reasons why it may be advantageous to have separate regulatory categories for each of these types. Refrigerated trailers have transport refrigeration units (TRUs) to provide climate control for their contents, such as perishable foods or electronics. These TRU refrigeration systems are typically powered by small engines, ranging from about 10 to 40 horsepower (California Air Resources Board 2003). Compared to dry van trailers, reefers are heavier due to structural differences and the roughly 2,000 extra pounds added by the TRUs (Thermo King 2013). Moreover, the placement of TRUs on the front side of trailers (i.e., in between the tractor and the trailer) can improve the aerodynamic performance of the tractor-trailer as the TRU acts as a pseudo-gap-reduction device. The baseline weight and aerodynamic characteristics of dry and refrigerated trailers are likely different enough to warrant separation in a regulatory classification scheme. Given that the working fluids for refrigeration systems can often be liquids with high global warming potential, the agencies could also institute a leakage standard for TRUs, as was done for HDVs in the Phase 1 regulation. Based on the potential to introduce specific leakage standards for TRUs, there is a strong case for creating a unique regulatory category for dry and refrigerated trailers.

Following this classification methodology, trailers would be segmented into three categories: two for box trailers—dry and refrigerated—and then one catch-all category for non-box trailers. An additional parameter by which to further subdivide trailers is length. Categorization by length would be beneficial, as it would allow the agencies to be more refined in setting stringency targets, since the fuel consumption reduction potential and expectations for technology uptake are not uniform across the various trailer lengths. For example, the technology potential for aerodynamic improvements is likely different for a 28-foot "pup" trailer than for a 53-foot trailer. Trailer market data from R.L. Polk organizes the trailer fleet by trailer type and by four length categories: 24 to 40 feet, 41 to 52 feet, 53 feet, and 54 to 65 feet (R.L Polk & Co., 2012). The 54 to 65 feet category represents less than 3% of total trailer sales, so it may be preferable to simply have a 53 feet or greater category, since 53-foot trailers themselves make up over 40% of total sales. A potential classification framework that segments according to three trailer types and three length categories is shown in Table 2. In this breakdown, dry box trailers of 53 feet or longer are the largest category, at roughly 37% of sales, and altogether dry box trailers represent nearly two-thirds of the market. The non-box segment is the next largest category, making up nearly a third of the trailer market. Refrigerated trailers are a relatively small category, with just over 3% of total sales.

Table 2: Example trailer classification structure and percent of total sales between January 2008 and December 2011

	24 – 40 feet	41 – 52 feet	53 feet or Longer	Total
Dry box trailers	20.5%	6.5%	36.7%	**63.6%**
Refrigerated box trailers	1.2%	0.4%	1.9%	**3.4%**
Non-box trailers	9.3%	17.1%	6.5%	**32.9%**
Total	**31.0%**	**23.9%**	**45.1%**	**100.0%**

2.2 AERODYNAMIC TESTING AND CERTIFICATION FOR BOX-TYPE TRAILERS

To determine the aerodynamic coefficient of drag (C_D) in the Phase 1 regulation, tractor manufacturers may use coastdown testing (a modified SAE J1263 procedure[1] that is referred to in the rule as the "enhanced coastdown procedure"), wind tunnel testing, or computational fluid dynamics (CFD) simulation. However, to address concerns about consistency and ensuring a level playing field, the enhanced coastdown 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 correlated to the reference method. As part of the aerodynamic certification process, the Phase 1 regulation specifies that each tractor must be paired with a "standard trailer" with no aerodynamic enhancements, as defined in Table V-2 of the regulation (U.S. EPA, 2011). The C_D values determined from testing are for the combination of tractor plus trailer.

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 certification methodology for tractors. After determining a C_D result from testing, the tractor is assigned a bin number based on the values in Table 3, and the corresponding C_D value in the lower portion on the table are the actual inputs into the Greenhouse Gas Emission Model (GEM), which is the official simulation tool used for vehicle certification for tractors and vocational vehicles.

Table 3: Aerodynamic input definitions to GEM for high-roof tractors in the Phase 1 regulation

	Class 7 day cab high roof	Class 8 day cab high roof	Class 8 sleeper cab high roof
Aerodynamic test results (C_DA in m^2)			
Bin I	≥ 8.0	≥ 8.0	≥ 7.6
Bin II	7.1 – 7.9	7.1 – 7.9	6.7 – 7.5
Bin III	6.2 – 7.0	6.2 – 7.0	5.8 – 6.6
Bin IV	5.6 – 6.1	5.6 – 6.1	5.2 – 5.7
Bin V	≤ 5.5	≤ 5.5	≤ 5.1
Aerodynamic input to GEM (C_D)			
Bin I	0.79	0.79	0.75
Bin II	0.72	0.72	0.68
Bin III	0.63	0.63	0.60
Bin IV	0.56	0.56	0.52
Bin V	0.51	0.51	0.47

To determine the fuel consumption and GHG standards for each tractor regulatory sub-category, the agencies set target adoption percentages for each of the five aerodynamic

1 See Section 3.2.2.1 of the 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 are tested in a bobtail (i.e., no trailer) configuration.

bins (as well as for the other technology areas such as tire rolling resistance and weight reduction). The adoption assumptions are shown below in Table 4; they are taken directly from Table III-4 in the Phase 1 regulation (U.S. Environmental Protection Agency 2011).

Table 4: Technology adoption percentages for tractors in the Phase 1 regulation

	Class 7		Class 8				
	Day cab		Day cab		Sleeper cab		
	Low/mid roof	High roof	Low/mid roof	High roof	Low roof	Mid roof	High roof
Aerodynamics (C_D)							
Bin I	0%	0%	0%	0%	0%	10%	0%
Bin II	40%	30%	40%	30%	30%	20%	10%
Bin III	50%	60%	50%	60%	60%	60%	70%
Bin IV	10%	10%	10%	10%	10%	10%	20%
Bin V	0%	0%	0%	0%	0%	0%	0%
Steer tires (C_{RR} kg/metric ton)							
Baseline	40%	30%	40%	30%	30%	30%	10%
Bin I	50%	60%	50%	60%	60%	60%	70%
Bin II	10%	10%	10%	10%	10%	10%	20%
Drive tires (C_{RR} kg/metric ton)							
Baseline	40%	30%	40%	30%	30%	30%	10%
Bin I	50%	60%	50%	60%	60%	60%	70%
Bin II	10%	10%	10%	10%	10%	10%	20%
Weight reduction (lb.)							
400 lb. reduction	100%	100%	100%	100%	100%	100%	100%
Extended idle reduction (gram CO2/ton-mile reduction)							
Automatic engine shutoff	N/A	N/A	N/A	N/A	100%	100%	100%
Vehicle speed limiter							
Vehicle speed limiter	0%	0%	0%	0%	0%	0%	0%

Given the high degree of interdependency between tractors and trailers, it seems highly advantageous to aim to align the test procedure and certification process for tractors and trailers as much as possible. Coastdown testing can be set as the reference test method, and trailer manufacturers would have the option of using wind tunnel and CFD testing at their discretion, provided that the test values are corrected according to the adjustment factor, which is determined by dividing the coastdown C_D results for a given trailer model by the simulation (i.e., wind tunnel or CFD) results for that same trailer model (see Equation 1).

The agencies can employ a similar aerodynamic binning approach for box-type trailers. As with tractors, the EPA and NHTSA can take advantage of much of the testing data that has been collected as part of the SmartWay program; this data is an excellent foundation for devising a binning framework that is reasonable for the current state of technology as well as future advancements that are expected in the area of trailer aerodynamics. One potential example of the breakdown of a five-bin strategy for box-type trailers is shown in Figure 1. Bin I would represent a baseline or standard configuration for a box-type trailer in which there are no additional aerodynamic features. Bin II is a fairly modest incremental improvement over the baseline and in this example is represented by the addition of a gap reduction device. The SmartWay program has certified certain gap reduction products to provide 1% or greater fuel savings. Bin III represents the current SmartWay-certified trailer, which has a side skirt (or underbody technology) or rear fairing that yields roughly of 4 to 6% in reduced fuel consumption. Bin IV trailers would likely need to employ both a side/underbody device and rear fairing to achieve 7 to 10% in fuel savings. Bin V represents advanced aerodynamic concepts that can achieve reductions in fuel use of greater than 10%. If indeed the agencies elect to pursue such a classification strategy, the exact granularity of the binning will require additional testing and careful consideration.

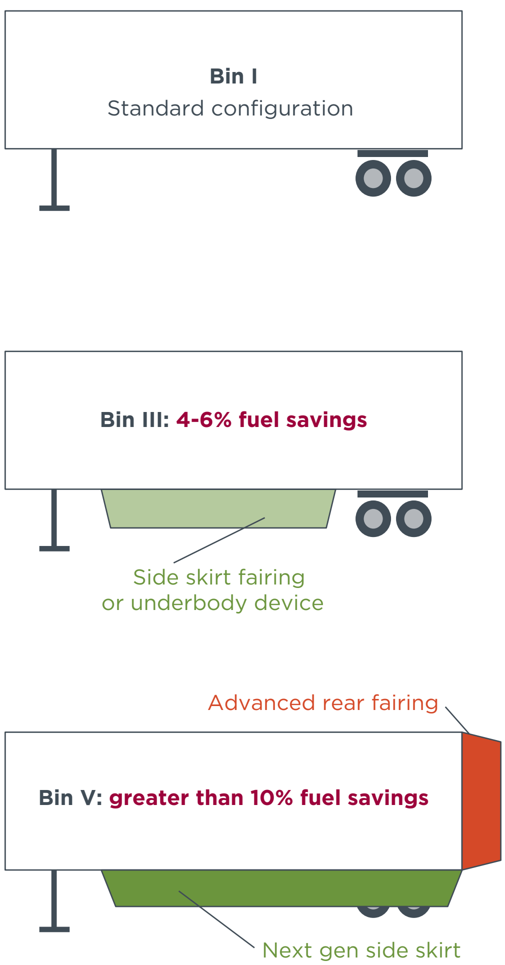

Figure 1: Example aerodynamic bin framework for box-type trailers

Similar to the Phase 1 regulation for tractors, the stringency of regulation for each trailer subcategory can be determined by setting target adoption percentages for each of the five aerodynamic bins (as well as for the other technology areas, such as tire rolling resistance and weight reduction). A depiction of the trailer classification and binning framework proposed in this paper is shown in Table 5. The percentages given in the table are purely illustrative and are meant to show that a similar methodology that was used to set the stringency across the tractor regulatory subcategories in the Phase 1 rule can be adopted for trailers in the Phase 2 regulation.

Table 5: Example technology adoption rates using the proposed trailer classification and binning methodology (values are for illustrative purposes only)

	24–41 feet			41–52 feet			53 feet or longer		
	Dry Box	Reefer	Non-box	Dry Box	Reefer	Non-box	Dry Box	Reefer	Non-box
Aerodynamics									
Bin I	0%	0%	-	0%	0%	-	0%	0%	-
Bin II	40%	40%	-	40%	40%	-	10%	10%	-
Bin III	60%	60%	-	60%	60%	-	60%	60%	-
Bin IV	0%	0%	-	0%	0%	-	20%	20%	-
Bin V	0%	0%	-	0%	0%	-	10%	10%	-
Tire rolling resistance									
Baseline	40%	40%	60%	40%	40%	60%	40%	40%	60%
Level I	50%	50%	35%	50%	50%	35%	50%	50%	35%
Level II	10%	10%	5%	10%	10%	5%	10%	10%	5%
Weight reduction (lbs)									
Control	200	200	-	300	300	-	400	400	-

2.3 TRACTOR SELECTION FOR TRAILER AERODYNAMIC CERTIFICATION

There are challenges that are inherent to performing coastdowns on a test track, such as variation in temperature, humidity, track surface conditions, and ambient wind speed. In addition, as evidenced by the tractor-trailer testing campaign sponsored by the ICCT in 2011, the specific tractor that is paired to a trailer can affect the determination of the aerodynamic coefficient of drag (Hausberger, Rexeis et al. 2011). The trailer testing campaign done by Hausberger et al. revealed that even two duplicate tractors (identical in terms of the make/model and all specifications) can yield slightly different C_D results when pulling exactly the same trailer.

To mitigate the challenge posed by the selection of the tractor used for coastdown (or wind tunnel or CFD) testing, there are different pathways that the EPA and NHTSA can pursue, each with advantages and disadvantages. In the first option, the agencies can provide detailed specifications for the tractor that is to be used for aerodynamic certification. There are some downsides to this approach. First, it seems that it would be difficult to develop comprehensive specifications for a tractor that would lead to roughly identical aerodynamic results for a given trailer model no matter which make/model of tractor the trailer manufacturer selected. Even for the most aerodynamic makes/models of tractors, there are variations in aerodynamic C_D values across different manufacturers. Second, it would likely be an additional burden to trailer manufacturers to have to acquire a tractor that exactly matches the specifications prescribed by the agencies. However, the primary benefit of this approach is that the agencies would have a reasonable amount of confidence that the choice of tractor will have minimal effects on the overall aerodynamic results for each trailer model.

Rather than requiring that each tractor used for aerodynamic testing meet certain specification criteria, a second option is to allow the trailer manufacturers the discretion to test with the tractor of their choice. However, the key difference in this strategy is that it would have to be an "A-to-B" testing approach in which a trailer model is tested against a baseline trailer, and the percentage difference versus the baseline is used as the metric for determining the trailer model's aerodynamic bin. As shown in Figure 2, the trailer manufacturer would be required to perform two coastdown (or wind tunnel or CFD) tests: one with the baseline model and the other with the more aerodynamic model. If a trailer manufacturer is certifying a standard trailer with no aerodynamic features, the agencies could allow manufacturers to avoid testing altogether and simply certify in GEM using the Bin I default value for C_D. This option is attractive, as it minimizes the tractor acquisition burden on trailer OEMs. However, the main pitfall of this approach is the fact that the choice of tractor can have significant effects on the marginal benefit of trailer aerodynamic features. In developing guidelines for their tractor-trailer GHG regulation, the California Air Resources Board (CARB) evaluated testing data and found that a tractor's aerodynamic profile has a significant impact on the overall C_D improvement achieved by the trailer technology. For example, tests with a less aerodynamic tractor (e.g., a tractor without fuel tank fairings) evidenced better overall C_D improvements from trailer aerodynamic features compared to tractors with better aerodynamics.

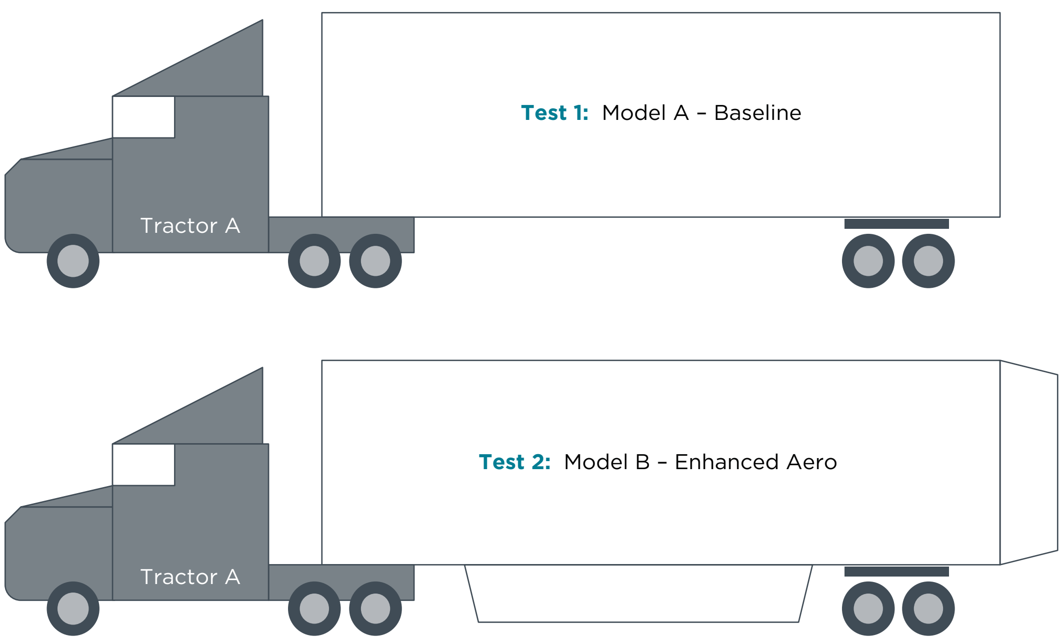

Figure 2: A-to-B trailer testing with the same tractor

A third option can potentially mitigate some of the negative aspects of each of the two aforementioned approaches. To alleviate the concern that trailer manufacturers may find it difficult to acquire a tractor that exactly matches the agencies' specifications (i.e., Option 1), an alternative strategy is to allow trailer manufacturers to choose any tractor that has been certified to a specific aerodynamic bin—say, for example, Bin IV, as defined in the Phase 1 regulation (U.S. EPA, 2011). The choice of tractor bin should best reflect the expectation of which bin will be the most prevalent over the course of the Phase 2 regulation (e.g., between 2020 and 2025). By limiting the choice of tractors for testing, the potential difference of C_D improvement between trailer aerodynamic technologies would be minimized and would also minimize the trailer manufacturer's ability to game the results.

To as much extent as possible, this A-to-B testing method that limits tractor selection to a specific aerodynamic bin minimizes the tractor's effect in determining the trailer's effect on the overall C_D. In this approach, a trailer model's aerodynamic bin designation would be determined based on an improvement percentage versus the baseline. In this approach, the agencies would need to specify the parameters for a baseline trailer, but seeing as this was already done as part of the Phase 1 regulation for tractors (see Table V-2 in the Phase 1 regulation (U.S. EPA 2011)), it seems that this could be extended to a trailer regulation fairly easily. Table 6 provides an example of how such a scheme might work (the values chosen are for illustrative purposes only).

Table 6: Example of how A-to-B trailer test results can translate to bin designations and C_D default inputs into GEM (values shown are for illustrative purposes only)

Reduction in C_D vs. baseline (from A-to-B test)	Bin designation	Default C_D input to GEM
	I	0.75
0-10%	II	0.68
10-20%	III	0.60
20-30%	IV	0.52
> 30%	V	0.47

2.4 YAW ANGLE

Given the relatively longer length/width ratio of a tractor-trailer compared with that of a passenger car, yaw angle (i.e., the angle at which a vehicle encounters wind, where zero degrees is wind in the exact direction of forward motion) is a very important factor in tractor-trailer aerodynamic drag. Figure 3 illustrates yaw angle for a tractor-trailer. The gap between the tractor and trailer, as well as the side and underbody of the trailer, can allow cross-flow of air during typical operating conditions, and this crosswind can have important implications for aerodynamic performance and fuel consumption.

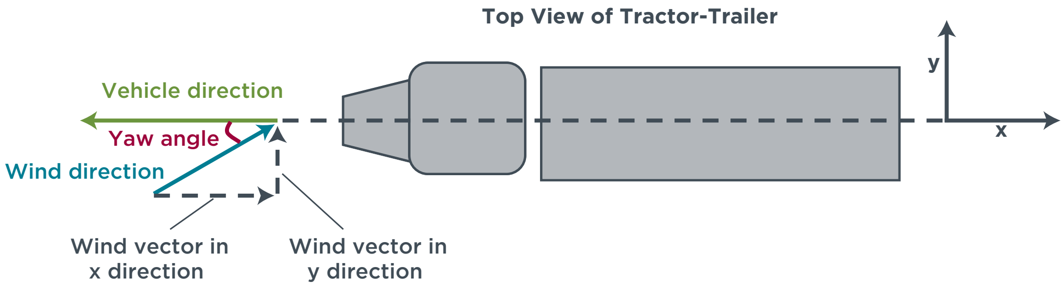

Figure 3: Cross wind and yaw angle

The EPA and NHTSA acknowledge that yaw angle has a sizeable impact on the fuel consumption of tractor-trailers in real-world conditions, but because wind tunnels and CFD simulation are currently the only methods available for assessing the influence of wind speed and direction, values of the coefficient of drag for tractors in the Phase 1 regulation nominally represent zero yaw.[2] However, as outlined in Section V.D.(3)(g) of the Phase 1 rule ("Aerodynamic Bin Category Adjustment Using Yaw Sweep Information"), the agencies finalized a provision to allow manufacturers the option of developing a "yaw sweep adjustment" to account for improved aerodynamics in crosswind conditions.

In this method for determining wind-averaged C_D (WAC_D), manufacturers test at 6, -6, and 0 degrees yaw and then can determine their final certified C_D value (for use in selecting the appropriate aerodynamic bin) using the correction steps below. As described earlier in the paper, coastdown testing is the reference test method in the Phase 1 rule for determining a tractor's aerodynamic performance, but manufacturers have the liberty to use wind tunnel or CFD testing and then apply an adjustment factor to correct the C_D value against the coastdown results. The adjustment factor is derived per Equation 1, in which an identical tractor model is coastdown tested and also wind tunnel or CFD tested, and then the adjustment factor is simply the C_D from the coastdown test divided by the simulation (i.e., wind tunnel or CFD) C_D results. In Equation 2, the adjustment factor is multiplied by the yaw sweep C_D results that were derived by simulating yaw angles of +6, -6, and 0 degrees. Due to the fact that the aerodynamic certification for tractors is premised on zero yaw, the wind-averaged, adjusted C_D (i.e., $C_{D\_adjusted\_wind\text{-}averaged}$) results from Equation 2 must be multiplied by a factor that relates wind-averaged C_D values to zero-yaw C_D values. This final correction is done in Equation 3, where the agencies set a default value of 0.8065 to represent the ratio of zero-yaw C_D to wind-averaged C_D results for a typical SmartWay-style high-roof sleeper tractor.

1. $$\text{Adjustment Factor} = \frac{C_{D\_coastdown}}{C_{D\_simulation}}$$

2. $$C_{D\_adjusted\_wind\text{-}averaged} = [\text{Adjustment Factor}] * C_{D\_wind\text{-}averaged}$$

3. $$C_{D\_adjusted\_zero\ yaw} * A = [C_{D\_adjusted\_wind\text{-}averaged} * A] * \frac{C_{D\_zero\ yaw\_industry\ average} * A}{C_{D\_wind\text{-}averaged\_industry\ average} * A}$$

$$= [C_{D\_adjusted\_wind\text{-}averaged} * A] * 0.8065$$

2 While the coastdown test protocol has limits on wind speed, there are no provisions on wind direction, and in real-world testing it would be nearly impossible to completely eliminate crosswinds.

It seems reasonable to assume that a similar provision can be implemented for trailers. Crosswinds have higher impact on trailers than they do on tractors, due to their greater length and the large area for underbody airflow (Ortega, Salari et al. 2013). Therefore, technologies that improve performance in crosswinds are that much more important for trailers. By having an option for including yaw angle in the test protocol for both tractors and trailers, the agencies can make it possible for manufacturers to receive the proper credit for aerodynamic features such as gap seals and cross-flow devices, which may have less benefits at zero-yaw conditions.

As in the Phase 1 regulation for tractors, inserting provisions in the Phase 2 rule for both tractors and trailers for optional wind tunnel or CFD testing under crosswind conditions would incentivize manufacturers to develop and deploy technologies that improve aerodynamic performance in crosswind conditions. This would encourage further advances in this often-overlooked area of tractor-trailer aerodynamics.

2.5 TIRES

Tire technologies continue to progress, and there are many trailer tire models (duals and single-wide tires) that offer low rolling resistance and thus contribute directly to fuel savings. With the growing availability of low rolling resistance tire models for trailers, there do not seem to be any technical barriers to creating a rolling resistance standard for all types of trailers. The EPA and NHTSA considered a case in which trailers were regulated for tire rolling resistance (U.S. EPA, 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.

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. As was done during the regulatory development process for the Phase 1 rule, the EPA and NHTSA can leverage the wealth of data and testing experience from the SmartWay program to support the development of the tire provisions in the standards for trailers.

In setting the fuel consumption and GHG targets for tractors in the Phase 1 rule, the agencies established a binning framework for tire rolling resistance values with three bins: “Baseline,” “Level I,” and “Level II.” Baseline represents average C_{RR} values, Level I is a 15% improvement and represents the threshold for SmartWay certification, and Level II is an additional 15% improvement beyond Level I and represents the best-in-class tires tested by the agencies at the time of the rulemaking. A similar binning approach can be used for trailer tires, and, as is illustrated in Table 4, the agencies can set adoption targets for each tire bin across all of the trailer regulatory subcategories.

2.6 WEIGHT REDUCTION

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. 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 of the vehicle, which can potentially allow for increased payloads and improved freight efficiency (i.e., the fuel required to transport a unit of payload over a given distance).

In the Phase 1 regulation, if tractor manufacturers use single-wide tires or aluminum wheels, or substitute aluminum or high-strength steel for other vehicle components, they can increase the payload weight used for fuel use and CO_2 certification in the GEM model by the amount that the actual truck weight is reduced as compared to the standard value. The complete list of weight reduction default values for tractors, which are based on material substitution, can be found in Table II-9 of the regulation (U.S. EPA, 2011). In Phase 1, the agencies estimate that, on average, a tractor can be made 400 pounds lighter by using material substitution such as aluminum in place of steel wheels and single-wide tires as replacements for duals tires.

An identical approach is recommended for trailers, in which manufacturers of box trailers can be credited for utilizing mass-reducing components based on a default look-up table. An example of such a table with default values for mass reduction components for trailers is presented in Table 7. The values are rough estimates, and the weight reduction items shown are not an exhaustive list and are for illustrative purposes only.

Table 7: Example of default values for box trailer weight reduction (values shown are for illustrative purposes only)

Weight reduction technology		Weight reduction (lbs.)
Single-wide tire with:	Steel wheel	80*
	Aluminum wheel	120*
Dual-wide tire with:	Steel wheel	10*
	Aluminum wheel	20*
Composite floor		250
Aluminum floor		650
Lightweight hub and drum		160
Aluminum cross-members		250
Lightweight landing gear		30
Composite side walls		400

* Weight savings per tire/wheel

2.7 CERTIFICATION METRIC

Determining an appropriate certification metric is an essential step in the regulatory development process for trailers. Although trailers certainly have an important impact on the overall fuel use and emissions of tractor-trailers, they themselves do not directly consume fuel or contribute emissions (except for the case of refrigerated trailers that have TRUs, which generally have a small diesel engine to power the system). As such, a grams of CO_2 (or fuel used) per ton-mile metric for trailers is somewhat non-intuitive, since the tractor is directly responsible for fuel use and CO_2 emissions. However, the advantages of fully aligning the certification metric for trailers with tractors and vocational vehicles outweigh this potential shortcoming.

As discussed in the previous sections, the methods for developing unique aerodynamic, rolling resistance, and weight reduction inputs into a GEM module for trailers can be based strongly on the approach already set forth for tractors in the Phase 1 regulation. Within the GEM trailer module, this input data can then used to simulate that particular trailer model with a *standard tractor*. Developing a standard tractor for use in the GEM simulations for trailer certification seems relatively straightforward. This standard tractor should reasonably represent an average tractor that is subject to the Phase 2 regulation. Using the standard tractor along with default payload values, the GEM simulation can output a grams/ton-mile (or gallons/ton-mile) result for each unique trailer model.

Given the high level of interdependence between tractor and trailers, having an identical certification metric is recommended in order to best integrate trailers into the Phase 2 regulation. Moreover, trailer credits for the ABT program should be in identical units (i.e., tons or gallons) to those used for the other vehicle categories. As with vehicles in the Phase 1 regulation, these credit (or debit) units for trailers can be derived using sales-weighting and average lifetime usage assumptions.

CONCLUSIONS AND RECOMMENDATIONS

To date, most policies that target trailer efficiency improvements have generally been voluntary. The U.S. EPA's SmartWay program has led a number of efforts 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 technology verification elements of the SmartWay program, the California Air Resources Board crafted a mandatory regulation for both tractors and trailers operating in California that is being phased in through 2017. For trailers, the rule includes provisions for both aerodynamic and rolling resistance improvements that will be phased in over the course of the decade. In integrating trailers into the Phase 2 regulation, policymakers at the EPA and NHTSA have the opportunity to build on the successes and experiences of both the SmartWay program and the CARB regulation.

Trailers represent a significant opportunity for cost-effective fuel savings and GHG reductions in the Phase 2 rulemaking for heavy-duty vehicles. In considering the mechanisms by which to test and certify trailers, much can be gleaned from the experience of Phase 1 regulation. As policymakers in the U.S. and Canada evaluate policy actions for trailers, 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 would greatly increase the fuel and GHG reductions of the program from cost-effective off-the-shelf technologies. The approximate potential benefits from trailers are approximately 8-12% per tractor-trailer, as compared to the 17-23% per tractor from the Phase 1 program that excludes trailers.

2. **Make trailer manufacturers a directly regulated entity within the overall heavy-duty vehicle regulatory program.** Regulating trailers primarily as a separate regulated entity, as compared to in a more directly integrated way within the tractor regulation or via credits, has two key advantages. First, there is increased certainty of adoption of fuel-saving trailer technologies, and second, this framework provides regulatory clarity for both tractor and trailer manufacturers.

3. **Develop a trailer classification framework that facilitates improvements in aerodynamics, tire rolling resistance, and lightweighting in box trailers as well as improvements in tire rolling resistance for all trailer types.** Regulating box trailers for all three technology areas—aerodynamics, tire rolling resistance, and lightweighting—will yield the majority of benefits from a trailer program. Tire rolling resistance standards can be introduced for all trailer types, and aerodynamic and weight reduction improvements in non-box trailers can be motivated through a crediting scheme. As with the Phase 1 regulation, policymakers should create a simple classification structure for trailers that is easily understood and avoids the complex task of creating regulatory subcategories within the non-box trailer category.

4. **Build on the success and experience of the Phase 1 regulation and align the testing and certification procedures for tractors and trailers as much as possible.** Assuming coastdown testing continues as the reference test method for tractors in the Phase 2 regulation, this test method should be used for trailers as well. Wind tunnel and CFD testing can also be allowed for trailers, provided that these results are normalized against coastdown test results. In addition, the optional provision in the Phase 1 regulation for testing tractors in crosswind conditions should be made

available for trailers as well. Finally, similar to the Phase 1 approach for tractors, an aerodynamic binning approach should be used for trailers. This scheme assigns default coefficient of drag (C_D) values for each aerodynamic bin and avoids manufacturers having to input test results from coastdown testing (or wind tunnel or CFD testing) directly into the GEM simulation tool. As with tractors, the GEM simulation program should be used for trailers for final certification.

5. **For trailer aerodynamic testing, pursue an "A-to-B" approach in which an identical tractor is used to test a baseline and an "enhanced" trailer in order to certify the enhanced trailer model's aerodynamic bin level.** The tractor used during trailer aerodynamic testing can have significant impacts on the coefficient of drag. To avoid the arduous task of creating detailed specifications for a "standard tractor," the agencies should base aerodynamic certification on an "A-to-B" testing approach, in which a trailer manufacturer uses one particular tractor to test both its baseline (i.e., no aerodynamic improvements) and an enhanced aerodynamic trailer.
6. **Utilize a grams/ton-mile (and functionally equivalent gallons/ton-mile) certification metric for trailers that is identical to the metric used for tractors and vocational vehicles in the Phase 1 regulation.** For maximum harmonization across the overall heavy-duty GHG regulation, the grams/ton-mile metric should be used for trailers. For the ABT program, credits and debits should be in tons (or gallons), as with the other vehicle categories.

These recommendations point toward a Phase 2 heavy-duty vehicle regulatory program for the U.S. and Canada that more comprehensively promotes known cost-effective technologies for tractor-trailers. We have seen the success of the early voluntary efforts from the SmartWay program as well as the California tractor-trailer GHG regulation drive trailer technology development, technology cost reductions, and increasing adoption of trailer technology. The regulatory approach recommended in this paper would offer a natural extension of the same policy principles but to wider fleet fuel saving and carbon emission benefits.

In North America and many places in the world, tractor-trailers represent the majority of fuel use and emissions from the on-road freight transportation sector. However, looking at heavy-duty vehicle regulations that have been finalized in the U.S., Canada, Japan, and China, none of these countries has yet elected to promote cost-effective trailer technologies at the same time as the known aerodynamic, engine, transmission, tire rolling resistance, and weight reduction technologies for tractors. The framework suggested in this paper not only offers benefits for trailer technology developers and trucking fleets in North America, but there could also be added value for policymakers in other venues as they grapple with ways to promote trailer fuel-saving technologies. In providing leadership in the area of policy design for trailers, the U.S. and Canada can potentially influence trailer regulatory development in other countries, and there can be increasing opportunity for better overall alignment of heavy-duty vehicle policies across jurisdictions. As discussed in a paper by the American Council for an Energy-Efficient Economy (Langer and Khan, 2013), one of the primary benefits of increasing levels of heavy-duty vehicle regulatory alignment across countries and regions is decreased regulatory compliance costs, which allows OEMs and technology suppliers to more easily bring fuel-saving technologies to market. Because aligned standards and certification methods can deliver cost benefits to manufacturers and consumers and promote a faster global adoption of fuel-saving technologies, they are seen as highly beneficial for industry, end users, and policymakers. In summary, strong policy action from the U.S. and Canada that promotes the development and deployment of efficiency technologies for trailers can have important effects both in North America and around the world.

The ICCT is engaged in a number of projects to continue analyzing the trailer market, technologies, and policy options. In a companion piece to this paper, we estimate the costs of trailer fuel-saving technologies as well as their current level of uptake in the market. This work was done in collaboration with the North American Council for Freight Efficiency and will provide data that assists the EPA and NHTSA in their evaluation of the costs and benefits of policy measures for trailers. In addition, there are also many relevant issues that must be considered in the near term as the agencies consider regulatory options for trailers. One such issue is a concern over the unintended consequences of the increased uptake of container chassis, which are less expensive than typical dry box trailers and have inferior drag characteristics and much less opportunity for aerodynamic improvements. Another important issue is the question of determining a “standard trailer” for tractor certification. In the Phase 1 regulation, a standard box trailer with no aerodynamic features must be used for coastdown testing, and tractors are also paired with a standard box trailer in GEM. If regulatory action is taken for trailers, it seems reasonable that the agencies will need to revisit the definition of a standard trailer, since there is evidence that suggests that tractor aerodynamic improvements are somewhat limited unless the tractor is designed to be paired with a trailer with aerodynamic enhancements (Golsch, 2013). The ICCT aims to continue to provide research and analysis that contributes to resolving these and other critical questions that can help strengthen heavy-duty vehicle policy in the Phase 2 regulation and beyond.

REFERENCES

California Air Resources Board (2003). Initial Statement of Reasons (ISOR) for Proposed Rulemaking: Airborne Toxic Control Measure for In-Use Diesel-Fueled Transport Refrigeration Units (TRU) and TRU Generator Sets, and Facilities Where TRUs Operate. Sacramento, CA: CARB.

Facanha, C., K. Blumberg, et al. (2012). Global Transportation Energy and Climate Roadmap: The Impact of Transportation Policies and Their Potential to Reduce Oil Consumption and Greenhouse Gas Emissions. Washington, DC: The International Council on Clean Transportation.

Golsch, K. (2013). GHG Phase II Regulation - Medium and Heavy Duty Vehicles: Duty Cycle Definition and Driver Modeling. Lisle, IL, Navistar International Co.

Hausberger, S., M. Rexeis, et al. (2011). Evaluation of fuel efficiency improvements in the heavy-duty vehicle (HDV) sector from improved trailer and tire designs by application of a new test procedure. Graz, Austria: Graz University of Technology, Institute for Internal Combustion Engines and Thermodynamics.

International Organization for Standardization (2009). Passenger Car, Truck, and Bus Tyres – Methods of Measuring Rolling Resistance – Single Point Test and Correlation of Measurement Results. Geneva, Switzerland. ISO 28580:2009(E).

Langer, T. and S. Khan (2013). International Alignment of Fuel Efficiency Standards for Heavy-Duty Vehicles. Washington, DC, American Council for an Energy-Efficient Economy.

Ortega, J., K. Salari, et al. (2013). Aerodynamic drag reduction of class 8 heavy vehicles: a full-scale wind tunnel study. Livermore, CA: Lawrence Livermore National Laboratory (LLNL).

R.L Polk & Co. (2012). New Commercial Trailer Registrations from January 2003 through December 2011 for trailers longer than 24 feet. Southfield, MI: R.L. Polk & Co.

Sharpe, B., N. Clark, et al. (2013). Trailer technologies for increased heavy-duty vehicle efficiency: Technical, market, and policy considerations. Washington, DC: The International Council on Clean Transportation.

Thermo King. (2013). "Thermo King Precedent Brochure." Retrieved December 16, 2013, from http://www.na.thermoking.com/content/dam/tki-na/pdf/brochures/trailer/55594_Precedent Brochure.pdf.

U.S. Environmental Protection Agency (2011). Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles. Federal Register, Vol. 76, Number 179. U.S. Government Printing Office.