UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY
2000 TRAVERWOOD DRIVE
ANN ARBOR, MI 48105-2498

OFFICE OF
AIR AND RADIATION

November 24, 2017

MEMORANDUM

SUBJECT: Stakeholder Meeting with Auto Alliance and Global Automakers and their contractor, Novation Analytics, and EPA Technical Response to Assertions of 'ALPHA-to-OMEGA Bias'

FROM: Kevin Bolon – Light-duty Vehicles and Small Engine Center
Assessment and Standards Division, Office of Transportation and Air Quality

TO: Docket EPA-HQ-OAR-2015-0827

This memo documents a meeting held on September 21, 2017 between representatives of The Alliance of Automobile Manufacturers (Alliance) and Global Automakers (Global), along with their contractor Novation Analytics (Novation), Inc., and EPA, as well as the National Highway Traffic Safety Administration (NHTSA) and California Air Resources Board (CARB). At this meeting, the Alliance and Global asked Novation to present the findings of a study contracted by the Alliance and Global on EPA's modeling of technology effectiveness in the November 2016 Proposed Determination (2016 PD.) In the presentation, Novation reported that the Lumped Parameter Model's translation of ALPHA vehicle simulation results introduced a systemic bias in CO_2 effectiveness values used in EPA's OMEGA fleet compliance modeling. In this memo, EPA summarizes the topics discussed at the meeting, and provides a synthesis of the materials published with the 2016 PD that are relevant to the question of whether or not there existed any such systemic bias. In sum, based on the detailed technical analysis described herein, the EPA concludes that the findings presented by Novation on September 21st are not consistent with EPA's 2016 Proposed Determination analysis and do not support the conclusion that the LPM introduces a systemic bias into EPA's analysis. EPA has identified several factors which contribute to the difference in conclusions. The purpose of this memo is to show EPA's assessment of these differences. The data and calculations used in EPA's is analysis are documented in the accompanying materials, along with the original data for the figures shown in this memo, and the Novation and EPA presentation materials from the September 21st meeting.

The attendees from The Alliance of Automobile Manufacturers included:

Chris Nevers – Vice President for Environmental Affairs
Michael Hartrick – Director of Fuel Economy and Climate

The attendees from Global Automakers included:

Julia Rege – Senior Manager, Environment and Energy
Amandine Muskus – Environment and Energy Manager

The attendees from EPA included:

Bill Charmley - Director, Assessment and Standards Division, ASD
Michael Olechiw – Director, Light-duty Vehicle and Small Engine Center, ASD
Robin Moran - Senior Policy Advisor, ASD
Kevin Bolon - Light-duty Vehicle Technology Team Leader, ASD
Dan Barba- Director, National Center for Advanced Technology
Joseph McDonald – Senior Engineer, ASD

The attendees from Department of Transportation/NHTSA included:

Jack Lyman - Attorney Advisor
Vinay Nagabhushana - General Engineer
Seiar Zia - General Engineer
Hannah Fish - Attorney Advisor

The attendees from CARB included:

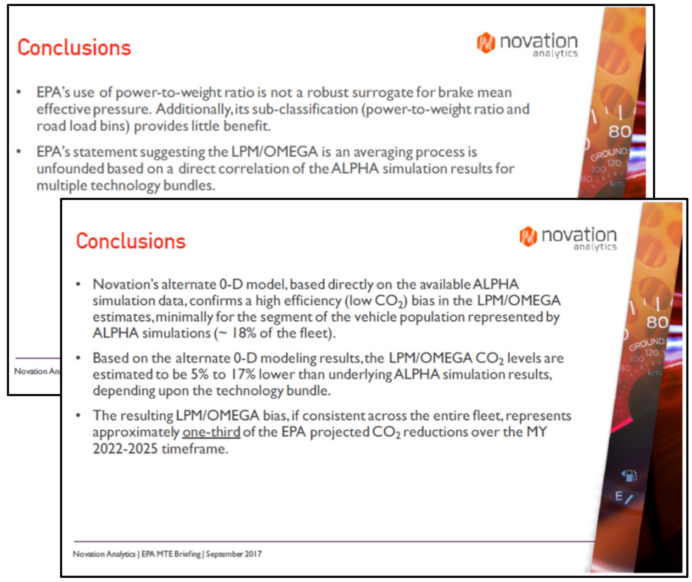
Mike McCarthy - Chief Technology Officer, ECARS Division
Pippin Mader - Air Resources Engineer, MLD
Cody Livingston - Air Resources Engineer, ACC Regulatory Section, ECARS
Shobna Sahni - Manager, ACC Regulatory Section, ECARS

The attendees from Novation Analytics included:

Greg Pannone – President, Novation Analytics
Michael Reale – Manager, Global Regulatory Analysis

Executive Summary

At the September 21st meeting, Novation Analytics presented the conclusions of their study of EPA's methodology for projecting CO_2 emissions of advanced technologies in the November 2016 Proposed Determination (2016 PD). This memo and attached materials document EPA's analysis of these conclusions, and include a full description of the model created by EPA based on the methodology presented by Novation. EPA's findings are summarized here.



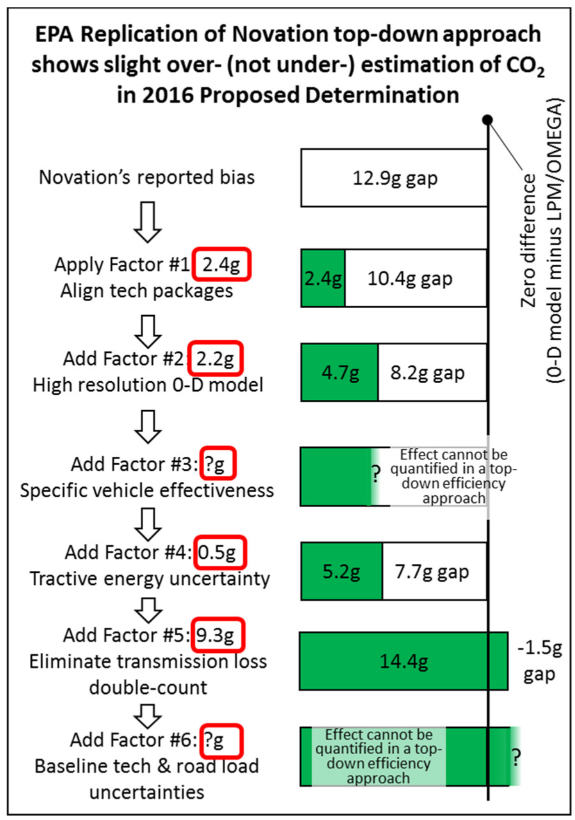
CO_2 Effectiveness Values: Novation asserted that in the 2016 PD, "EPA did not provide proof that the LPM/OMEGA process produces 'both small over-estimates and small under-estimates' " which on average align with the ALPHA simulation results. As part of their process, Novation attempted to re-create Figure 2.100 from EPA's Technical Support Document, which compares Lumped Parameter Model (LPM) effectiveness values with ALPHA effectiveness values for a number of individual vehicles. However, it appears that Novation may not have accounted for the effect of (a) the presence of technologies in future OMEGA packages that were not represented in the published ALPHA results, such as low drag brake technology and secondary axle disconnect for four-wheel drive vehicles, (b) LPM power-to-weight adjustment factors which are used when applying technology effectiveness values to specific vehicles, or (c) the technology content of the baseline packages.

For this memo, EPA re-created an analysis similar to Figure 2.100, but containing more vehicle models and using an approach that can be replicated by stakeholders without requiring any information beyond what was published with the 2016 PD. The results show that effectiveness values generated by LPM are within 0.3 percent of the published 2016 PD ALPHA results on average, and generally within a range of $\pm$ 2 percent.

Powertrain Efficiency and Absolute CO_2 Values: Novation asserted that there is a "high efficiency (low CO_2) bias in the LPM/OMEGA estimates" with CO_2 results "estimated to be 5% to 17% lower than underlying ALPHA simulation results," which "represents approximately one-third of the EPA projected CO_2 reductions over the MY 2022-2025 timeframe." Novation came to this conclusion by creating an alternate 0-D model to represent ALPHA runs, and compared the model to the MY2025 OMEGA results. While this powertrain *efficiency* approach was not intended by Novation to be a replacement for the bottom-up *effectiveness* approach required for EPA's compliance cost assessments, EPA recognizes the value of a top-down efficiency approach as a quality assurance tool. For this memo, EPA attempted to replicate Novation's conclusion by creating a 0-D model using the methodology described by Novation, paying careful attention to maintaining the appropriate assumptions when applying results and data intended for a bottom-up *effectiveness* approach to an analysis using an *efficiency* approach.

In contrast to Novation's conclusion that LPM/OMEGA underestimates ALPHA CO_2 values by 13 g/mi (i.e. 12.9 g/mi sales-weighted average of the technology packages represented in Novation's reported 5% to 17% range), EPA found that there is no evidence of any bias in the LPM representation of ALPHA CO_2 values for the 2016 PD analysis. There are multiple factors which have apparently contributed to the difference between Novation's and EPA's conclusions, the effects of which can be approximately quantified using the Novation methodology and information published by EPA for the 2016 PD. These include the consistency of the content of technology packages being compared (Factor #1), the degree of resolution used to represent the published ALPHA model results (Factor #2), the degree of uncertainty in estimating tractive energy intensity of future vehicles (Factor #4), and the appropriateness of using ALPHA CO_2 numbers intended for quantifying technology *effectiveness* in an analysis using a top-down *efficiency* approach (Factor #5.) The combined effect of these factors can entirely explain the apparent 12.9 g/mi bias reported by Novation. Two additional factors which cannot be assessed using an efficiency approach are outside of the scope of this memo, but are the subject of ongoing work by EPA involving ALPHA modeling. These include the appropriate application of ALPHA effectiveness values to specific vehicles (Factor #3), and the appropriate characterization of road loads and technologies in the baseline fleet (Factor #6.)

Of the four factors contributing to Novation's conclusions that are quantified in this memo by EPA, one factor (#5) was dominant and merits further discussion here; the inappropriateness of using the published ALPHA runs for LPM *effectiveness* calibration to represent *absolute CO_2* values. In particular, EPA had reported in the 2016 PD that these ALPHA runs contained a double counting of transmission neutral drag losses, which are contained both in the coast down coefficients and the transmission loss maps. Because this double-count results in a slightly conservative assumption for *effectiveness*, and there was some uncertainty on the appropriate correction, EPA opted to maintain the double-count in the 2016 PD analysis. However, in response to Novation's analysis, EPA attempted to quantify the effect of the double-count on a fleet-wide basis. Adjusting the 0-D model based on this quantification resulted in a very close match between the ALPHA and LPM/OMEGA results, with a very slight over-estimation of CO_2 in the LPM/OMEGA estimates of 1.5 g/mi, rather than a 12.9 g/mi under-estimation as asserted by Novation.



Power-Weight Ratio: Novation asserted that the "EPA's use of power-to-weight ratio is not a robust surrogate for brake mean effective pressure." In support, Novation presents correlations between power-to-weight ratio and fuel consumption, and between displacement specific tractive energy and displacement specific fuel energy, noting that the displacement specific energy domain provides a significantly higher correlation than power-to-weight ratio.

However, the primary reason for the correlation difference is not the use of power-to-weight ratio, but rather the use of raw fuel consumption rather than normalized fuel consumption. The EPA analysis for the PD is done using effectiveness, or percent decrease in CO_2, and the use of normalized fuel consumption is consistent with that methodology. Normalizing fuel consumption increases the correlation from 41 percent (Novation's claim) to about 87 percent. Although EPA agrees that inclusion of a factor accounting for road loads in addition to inertial effects (i.e., weight) would be more robust, the use of displacement as a normalizing factor is mathematically identical to the use of engine power when performance neutrality is maintained by maintaining power-to-weight ratio (per the Novation methodology) and powertrains having different specific powers are separated, as in the EPA methodology.

Conclusion: Because EPA estimates the costs of adding technologies to existing vehicles to achieve compliance, a bottom-up analysis of incremental improvements in CO_2 effectiveness is required to ensure consistency with the estimated costs. In their analysis, Novation presented a top-down approach to examining powertrain efficiency and CO_2 values, and concluded that LPM/OMEGA introduces a bias when representing the ALPHA results. EPA has conducted an analysis, the details of which are provided in this memo and the supporting materials, and concludes that there is no evidence of bias in the LPM/OMEGA representation of ALPHA model results. The *CO_2 effectiveness* values simulated in ALPHA fall generally within $\pm$ 2 percent of LPM values, and within 0.3 percent on average. *Absolute CO_2* values produced by the LPM are unbiased relative to ALPHA, and for the subpopulation of vehicles included in Novation's analysis, LPM CO_2 values are 1.5 g/mi *higher than* the CO_2 values produced by EPA's 0-D model of published ALPHA results, rather than 12.9 g/mi lower as asserted by Novation.

Overview

At the September 21st meeting, Novation Analytics presented the conclusions of their study of EPA's methodology for projecting CO_2 emissions of advanced technologies in EPA's January 2017 Final Determination (2017 FD) on the appropriateness of the MY2022-2025 GHG standards. Novation's conclusions (presented on slides 42 and 43) were as follows:

- "EPA's use of power-to-weight ratio is not a robust surrogate for brake mean effective pressure. Additionally, its sub-classification (power-to-weight ratio and road load bins) provides little benefit."

Topic of memo Section 3

- "EPA's statement suggesting the LPM/OMEGA is an averaging process is unfounded based on a direct correlation of the ALPHA simulation results for multiple technology bundles."

Topic of memo Section 1

- "Novation's alternate 0-D model, based directly on the available ALPHA simulation data, confirms a high efficiency (low CO_2) bias in the LPM/OMEGA estimates, minimally for the segment of the vehicle population represented by ALPHA simulations (~ 18% of the fleet)."
- "Based on the alternate 0-D modeling results, the LPM/OMEGA CO_2 levels are estimated to be 5% to 17% lower than underlying ALPHA simulation results, depending upon the technology bundle."
- "The resulting LPM/OMEGA bias, if consistent across the entire fleet, represents approximately one-third of the EPA projected CO_2 reductions over the MY 2022-2025 timeframe."

Topic memo Section 2

As part of the on-going assessment of the light-duty GHG standards, EPA has reviewed the conclusions and underlying methodology presented by Novation, as well as the data used by EPA to inform the 2016 Proposed Determination. Note that in preparing this quantitative review, EPA is utilizing only the data and tools that were published at the time of the 2016 Proposed Determination and therefore publicly available since November 2016. While EPA has continued to update the technical analysis since that time, any updates to the data or the use of revised tools are not reflected in the quantitative analysis in this memo.

The remainder of this memo is structured around the Novation conclusions as listed above. Section 1 revisits the statement made by EPA in the 2016 PD TSD that "the LPM is able to reliably replicate the effectiveness values generated by the physics-based ALPHA model (within 2%) over a wide range of vehicle classes, technologies, and powertrain efficiency values." In Section 2, EPA investigates the Novation-reported "high efficiency (low CO_2) bias in the LPM/OMEGA estimates" using an EPA version of the 0-D model described by Novation at the September 21st meeting. Finally, in Section 3, EPA contrasts two different approaches for determining the appropriate CO_2 benefits when applying technology to specific vehicles; the power-to-weight approach employed by EPA in the 2016 PD, and the displacement specific tractive energy approach advocated by Novation. Appendices A and B contain additional detail regarding EPA's 0-D modeling used in this memo.

1. Alignment between ALPHA and LPM for CO_2 effectiveness values and review of Figure 2.100 from the 2016 PD TSD

In the Technical Support Document (TSD) for EPA's November 2016 Proposed Determination, EPA presented a comparison of technology effectiveness values for 36 vehicles to illustrate that the LPM reliably represents the effectiveness values for technology packages as determined by the ALPHA model. Figure 2.100 of the TSD shows that LPM-generated effectiveness values are centered about the effectiveness values of corresponding technology packages produced by ALPHA, and fall within a narrow range. EPA concluded that the results shown in Figure 2.100 "confirm that the LPM is able to reliably replicate the effectiveness values generated by the physics-based ALPHA model (within 2%) over a wide range of vehicle classes, technologies, and powertrain efficiency values." Because the data shown in Figure 2.100 represent specific vehicles (road loads and test weights), performing this quality assurance check required additional ALPHA runs beyond the LPM calibration runs that were published with the 2016 PD.

Novation's conclusion in the September 21st meeting that "EPA's statement suggesting the LPM/OMEGA is an averaging process is unfounded based on a direct correlation of the ALPHA simulation results for multiple technology bundles" is based primarily on an unsuccessful attempt by Novation to replicate the conclusions of Figure 2.100. As this section will show, there are two important considerations which, if ignored, would make it impossible to reconstruct an apples-to-apples comparison of effectiveness values as shown in Figure 2.100. The first consideration is the need to align the content of both the starting and ending technology packages when conducting any sort of comparison of effectiveness values. The second consideration is the need to consistently represent the methodology of applying effectiveness values from the exemplar[1] vehicles modeled in ALPHA to the individual vehicles represented in the LPM/OMEGA fleets. This section will show the significance of ignoring these considerations, as apparently was done in Novation's review of Figure 2.100. In doing so, EPA is providing here a methodology that stakeholders can use to generate a comparison of effectiveness values similar to the Figure 2.100 without the need for any additional ALPHA runs, using only the data that was published at the time of the November 2016 Proposed Determination.

[1] Exemplar vehicles are defined based on the road load, test weight, and power-to-weight characteristics for each ALPHA class, and are used as a basis from which to apply ALPHA simulation results to individual vehicles based on their particular characteristics. See the Technical Support Document for the 2016 Proposed Determination for more details.

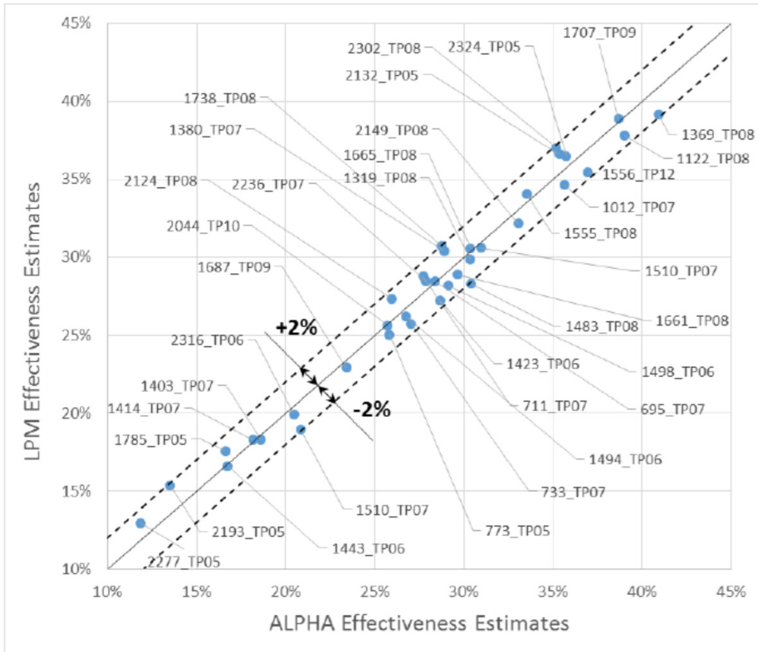


Figure 2.100 LPM and ALPHA Package Effectiveness Comparison for Vehicles and Throughout Distribution of Powertrain Efficiencies

Figure 1 LPM and ALPHA Effectiveness Comparison as presented in Figure 2.100 of the 2016 Proposed Determination Technical Support Document

Process used in this memo for comparing effectiveness values

In the first step, EPA selected all the vehicles in the PD OMEGA compliance analysis where both the engine and transmission are represented in the published ALPHA results for both the MY2015 baseline (TP00) and MY2025 future tech packages. Depending on whether or not Stop-Start packages are included, the selected subpopulation of vehicles includes 241 models (146 without Stop-Start), and covers 17 percent (15 percent without Stop-Start) of the total volume of non-electrified powertrains in the MY2025 fleet, as shown with highlighting in Table 1.

Table 1 Vehicle population from 2016 PD OMEGA analysis used for this effectiveness comparison

Engine/Trans	MY2025 Volumes				MY2025 w/data and w/ TP00 represented in ALPHA results			
	Including Stop-Start		Excluding Stop-Start		Including Stop-Start		Excluding Stop-Start	
	All	w/data	All	w/data	Vol	Veh Count	Vol	Veh Count
GDI+TRX11/12/21/22	523,835	522,904	480,510	479,579	522,904	28	479,579	26
ATK2+TRX11/12/21/22	3,504,088	2,944,336	2,537,316	2,370,711	1,599,487	142	1,367,308	120
TDS24+TRX11/12/21/22	347,567	253,638	104,308	104,308	28,172	71	-	-
Subtotal	**4,375,491**	**3,720,878**	**3,122,135**	**2,954,599**	**2,150,564**	**241**	**1,846,887**	**146**
Total non-electrified[1]	**12,669,254**							

[1] **Total includes diesel, PFI, deac, 18 bar turbo, MT and 4-speed transmissions that are not reported in published ALPHA results. Does not include MHEVs, HEVs, EVs.**

In the September 21st presentation, Novation described their attempt to reproduce Figure 2.100 and correctly observed that the technologies present on the 36 points shown in Figure 2.100 do not correspond exactly to the packages produced by OMEGA's compliance analysis for the 2016 PD (slide 21.) This was intentional and necessary to generate the data for Figure 2.100, as EPA had to remove the effectiveness benefits of technologies not represented in the ALPHA results in order to appropriately compare the LPM output to ALPHA simulation results. In addition to the need to align the end-point technology package contents between the LPM and ALPHA, the technology content of starting packages must also be aligned in oder to ensure a valid comparison of incremental effectiveness.

To calculate appropriate LPM effectiveness values (corresponding to the y-axis of Figure 2.100), EPA first ensured that the content of the technology packages to be compared was aligned with the published ALPHA runs. This was achieved by using the published LPM (Excel version) to remove the CO_2 benefit of technologies present in the MY2025 OMEGA fleet but not represented in the published ALPHA results. Specifically, the benefits of Low Drag Brakes, Secondary Axle Disconnect, and Stop-Start were removed. In addition, the published ALPHA models for gasoline direct injection (GDI) engines and 13:1 Compression Ratio Atkinson (ATK2[2]) cycle engines are representative of current MY2015-vintage applications while the final OMEGA results are representative of future model year applications, which have additional technology improvements. Therefore, the efficiency improvements associated with these additional technologies, which include future levels of engine friction reduction (EFR2) and improved accessories (IACC2) included in the final OMEGA packages, were removed (again using the 2016 PD published Excel version of the LPM) to match the technologies represented by the ALPHA results. The resulting 'aligned' packages have lower efficiency (higher CO_2) than the actual LPM/OMEGA packages. These adjustments, summarized in Table 2, were performed for each vehicle and technology package considered in the PD analysis, including the MY2015 baseline packages and all candidate packages considered in the MY2025 control case.

Table 2 Effectiveness benefits removed from LPM/OMEGA results for consistency with published ALPHA technology packages

Powertrain Description	Technologies present in LPM/OMEGA packages, but not in published ALPHA packages	
	Powertrain Technologies	Vehicle Technologies
SI,NA (GDI+TRX11/12/21/22 without DEAC)	Advanced engine friction reduction (EFR2), Improved Accessories (IACC2), Stop-Start (SS)	Low Drag Brakes (LDB), Secondary Axle Disconnect (SAX)
SI, Atkinson2 (ATK2+TRX11/12/21/22 w/ & w/o DEAC, w/ & w/o CEGR)	Stop-start (SS)	
SI, 24bar BMEPTC (TDS24+TRX11/12/21/22)		

To calculate the appropriate ALPHA effectiveness values for individual vehicles (corresponding to the x-axis of Figure 2.100), EPA began by directly calculating CO_2 effectiveness from the published ALPHA results as the percentage improvement from the baseline (TP00) to future technology packages. Because these published ALPHA results used for the calibration of LPM effectiveness values are representative of exemplar vehicles rather than representative of the individual vehicles in the fleet, EPA applied the power-to-weight effectiveness adjustment factors published in the 2016 PD TSD to calculate individual vehicle ALPHA effectiveness.[3] This adjustment was necessary to ensure an apples-to-apples comparison, since the CO_2 values output from the published LPM (Excel version) have already been adjusted for differences in power-to-weight ratio relative to the exemplar.

Results

[2] In EPA's 2016 Proposed Determination analysis engines operating using Atkinson cycle in non-hybrid applications was designated as "ATK2". For more information refer to the Technical Support Document for the 2016 PD.

[3] Power-to-weight effectiveness adjustment is implemented in the published LPM Excel code, and described in Table 2.55 and accompanying text of the 2016 PD TSD.

The results shown in Figure 2 cover the 146 vehicles (11 percent of MY2025 total volume) without Stop-Start which satisfy the requirement that the content of the aligned LPM packages matches exactly with a published ALPHA run for both the starting and ending packages.

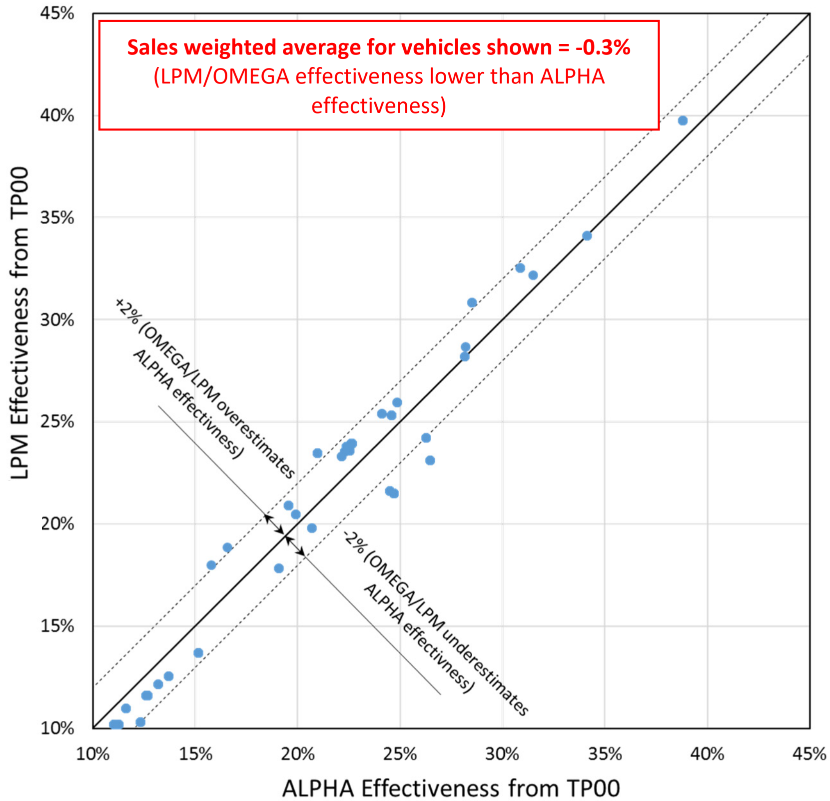


Figure 2 LPM and ALPHA Effectiveness Comparison for 146 Vehicles with non-electrified SI Powertrains (without Stop-Start in Original Package Definitions)

To create an expanded version of the effectiveness comparison shown in Figure 2, EPA increased the number of vehicles considered by including vehicle packages with Stop-Start. As in Figure 2, the effectiveness for Low Drag Brakes and Secondary Axle Disconnect were removed to align with ALPHA results. In addition, the effectiveness benefit of Stop-Start was also removed using the published LPM. The resulting set of vehicles shown in Figure 3 covers 241 vehicles (13 percent of MY2025 total volume.)

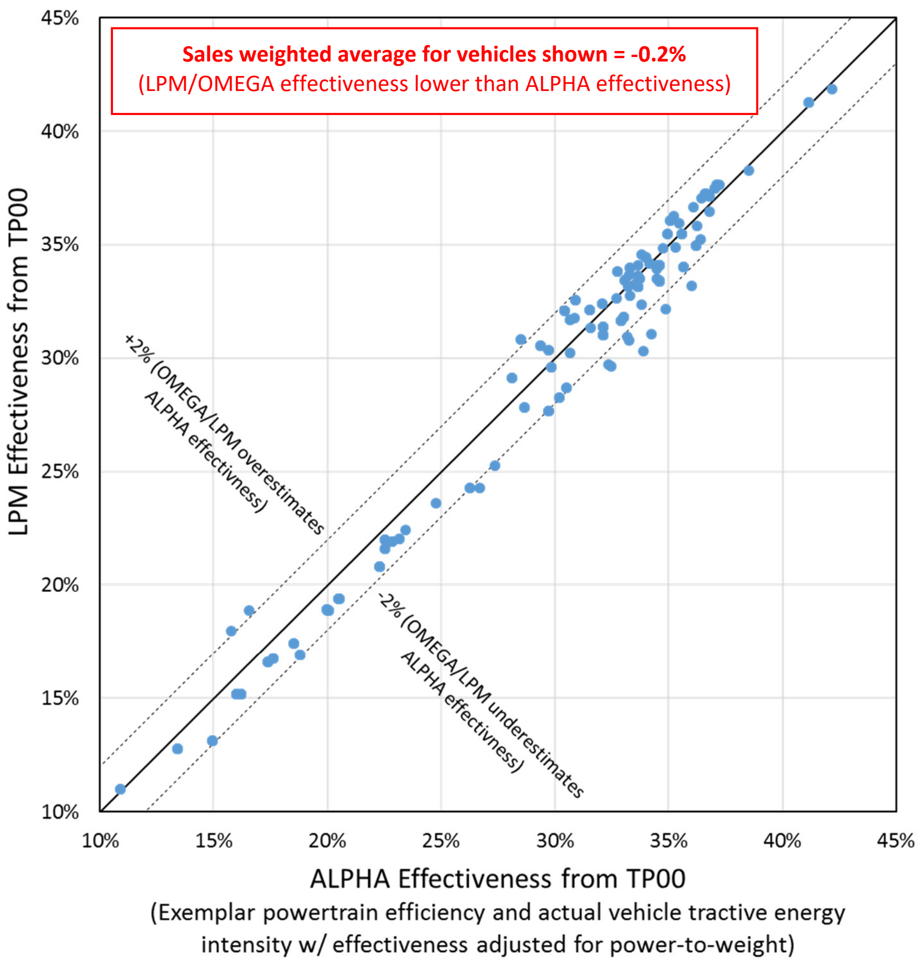


Figure 3 LPM and ALPHA Effectiveness Comparison for 241 Vehicles with non-electrified SI Powertrains (both with and without Stop-Start in Original Package Definitions)

The results shown in Figure 2 and Figure 3 are consistent with the conclusions from Figure 2.100 of the 2016 PD; that LPM effectiveness values are generally within ± 2 percent of the ALPHA effectiveness values, and overall, the LPM represents the ALPHA results without a high effectiveness bias (sales-weighted average effectiveness from LPM is within 0.3 percent of, and in this case lower than, the average ALPHA effectiveness value.) Furthermore, the distribution of the data is consistent with the results that were shown in Figure 2.100 of the PD.

To contrast, EPA reran the analysis with the same set of vehicles shown in Figure 3, but without removing the additional effectiveness associated with technologies not represented in published ALPHA results. The technology contents of the resulting sets of packages are not aligned, making the comparison (shown in Figure 4) invalid. As expected, the effectiveness values of the unaligned packages present a much poorer correlation. In this case, the indicated LPM effectiveness values are more often 2 percent or more higher than the ALPHA effectiveness values, and the overall sales-weighted average of LPM effectiveness values is 0.5 percent higher than the average ALPHA effectiveness.

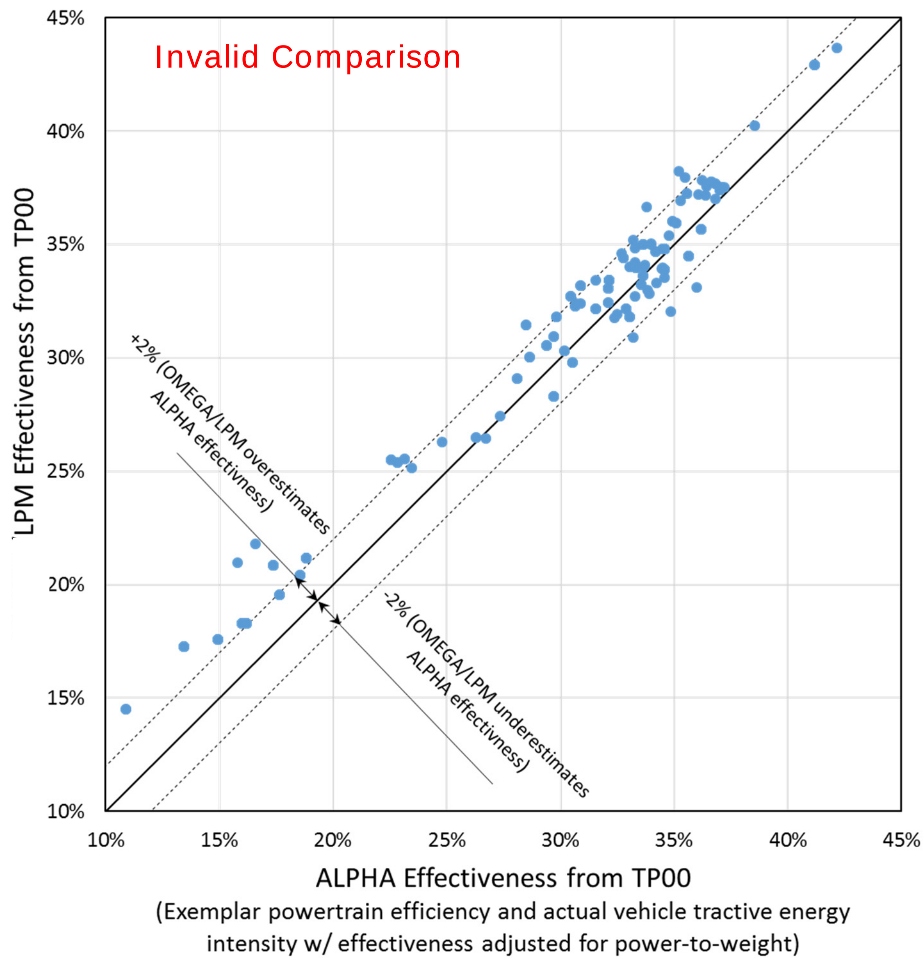


Figure 4 Effect of non-alignment of technology package content

Key takeaway: *When the technology package content of the corresponding starting and ending packages are <u>not</u> aligned, CO_2 effectiveness values generated by LPM would appear to be generally higher than effectiveness values based on the published 2016 PD ALPHA (LPM is 0.5% higher on average)*

EPA again reran the analysis with the same set of vehicles shown in Figure 3, this time without applying the appropriate without power-to-weight adjustment, as well as without removing the additional effectiveness associated with technologies not represented in published ALPHA results. In this case (shown in Figure 5), the effectiveness values of the unaligned and unadjusted packages present an even poorer correlation.

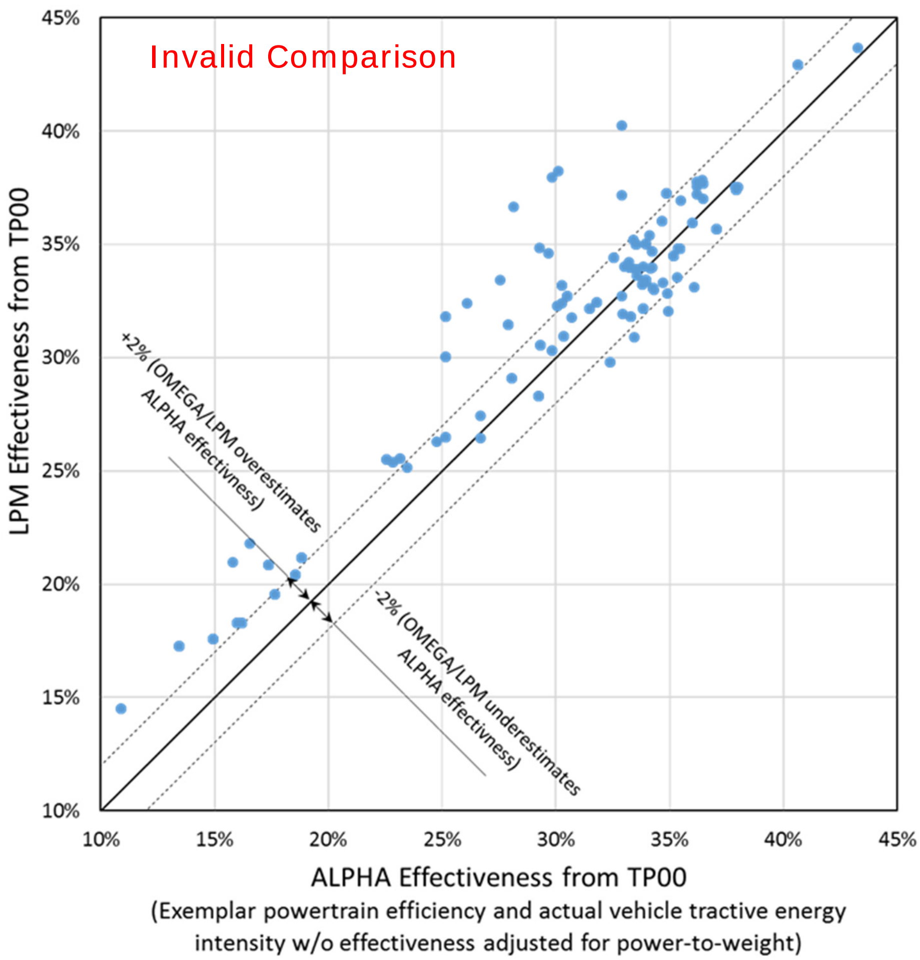


Figure 5 Effect of non-alignment of technology package content +
Use of exemplar vehicle ALPHA results without power-to-weight adjustment

Key takeaway: *When the technology package content of the corresponding* <u>*starting and ending packages are not aligned*</u> ***and*** <u>*power-to-weight adjustment factors are not applied*</u>*, CO_2 effectiveness values generated by LPM would appear to be as much as 8 percent higher than effectiveness values based on the published 2016 PD ALPHA (LPM is 0.6% higher on average)*

Conclusions

In the September presentation, Novation cited EPA's text from the PD TSD that "[EPA's approach] will produce both small over-estimates and small under-estimates of technology effectiveness" and stated in slide 22 that "EPA did not provide proof that the LPM/OMEGA process produces '*both small over-estimates and small under-estimates*', nor did it define '*small*' and show that these errors '*average out*'."

The above analysis is intended to provide additional clarification that the small deviations in effectiveness between the LPM and ALPHA models, specified here as ±2 percent, do average out. Specifically, Figure 2 and Figure 3 both show that when considering all of the vehicles and OMEGA pathways in the 2016 PD analysis that begin and end with technology packages which are represented in the published ALPHA results, that 1) the LPM effectiveness values are generally within ± 2 percent of the ALPHA effectiveness values, and 2) the overall sales-weighted average effectiveness from LPM is within 0.3 percent of (and in this case lower than) the average ALPHA effectiveness value. The distribution of the data is consistent with the results that were shown in Figure 2.100 of the PD.

Key takeaway: *When the technology package content of the corresponding starting and ending packages are aligned, CO_2 effectiveness values generated by LPM match effectiveness values based on the published 2016 PD ALPHA (LPM is 0.2% lower on average, and generally within a range of ± 2%.)*

2. Alignment between LPM/OMEGA and ALPHA for powertrain efficiency and absolute CO_2 values

In the September 21st meeting, Novation described their Alternate 0-D model based on the ALPHA results published by EPA for the 2016 PD, and reported that the model "confirms a high efficiency (low CO_2) bias in the LPM/OMEGA estimates."[4,5] Novation then projected this reported bias to the full fleet, concluding that "if consistent across the entire fleet, [the LPM/OMEGA bias] represents approximately one-third of the EPA projected CO_2 reductions over the MY2022-2025 timeframe." As described in Section 1 above, LPM/OMEGA modeling generates unbiased CO_2 effectiveness values relative to the published ALPHA results when care is taken to ensure alignment between the content of the respective beginning and ending technology packages. Given that the LPM/OMEGA is appropriately representing the ALPHA model's incremental percentage reduction in CO_2 emissions, the goal of this section is to identify the existence of, and possible explanations for, any differences in powertrain efficiency and absolute CO_2 values between the LPM/OMEGA results and the published ALPHA results.

As background to this discussion of powertrain efficiencies, it is important to consider that the basis for EPA's "bottom up" analysis is grounded in the requirement that EPA estimate the costs of adding technologies to existing vehicles to achieve compliance. Thus, to ensure consistency with the estimated costs, EPA's future CO_2 values are determined by applying CO_2 improvements relative the baseline vehicles, considering the technology that is already present in those vehicles. In contrast, if one were to set aside the requirements of cost-estimation, a "top-down" approach can be used to evaluate the feasible efficiencies of future powertrains without any consideration of the baseline fleet technologies and efficiencies.

In the incremental, bottom-up approach, EPA assesses technology in terms of CO_2 effectiveness, which is a measure, expressed as a percentage, of a technology's ability to reduce CO_2 emissions from a vehicle absent the technology. Because CO_2 effectiveness is an incremental measure, the final CO_2 value is a function of both the effectiveness value used to represent a future technology package, and the starting CO_2 value of the baseline technology package. Furthermore, the applied effectiveness value will depend on an appropriate characterization of the baseline vehicle's technology package content. Effectiveness should not be confused with efficiency, which is a measure of the amount of useful work done with a given amount of energy, and is an absolute metric, not an incremental one. The efficiency of a future technology package is independent of the baseline vehicle's technology package content and CO_2 value. The distinction between effectiveness and efficiency is cataloged in Table 3, and the

[4] Novation 9/21/2017 presentation (slide 43) "based on the alternate 0-D modeling results, the LPM/OMEGA CO2 levels are estimated to be 5% to 17% lower than underlying ALPHA simulation results."

[5] Novation 9/21/2017 presentation (slide 39) "the resulting vehicle sub-population [modeled in the Alternate 0-D model] yields efficiency levels that are 5.5% to 14.7% lower than the LPM/OMEGA assessment."

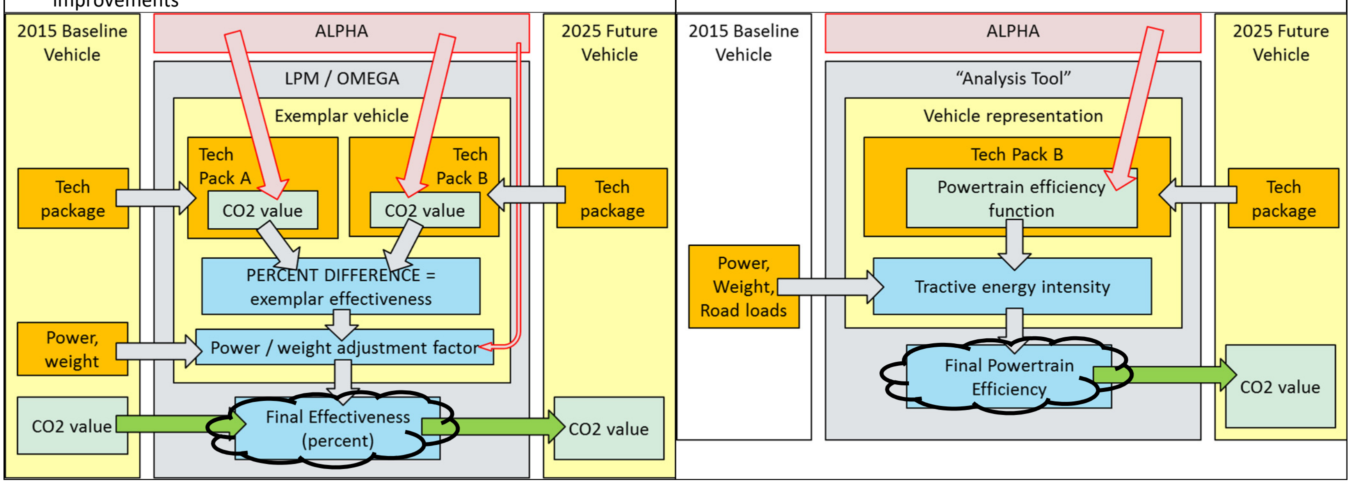
application of the two metrics in the bottom-up and top-down approaches, respectively, is summarized in Table 4.

Table 3 Distinction between 'CO_2 Effectiveness' and 'Powertrain Efficiency'

CO_2 Effectiveness	Powertrain Efficiency
• is a measure, expressed as a percentage, of a technology's ability to reduce CO2 emissions from a vehicle absent the technology • is an ***incremental*** measure, and therefore is a function of the ***final and starting*** technology packages • is defined by the equation: $CO_2\ Effectiveness = \frac{CO_{2,TPstarting} - CO_{2,TPfinal}}{CO_{2,TPstarting}}$	• is a measure of the amount of useful work done by the powertrain with a given amount of energy • is an ***absolute*** metric, and therefore is a function of ***only the final*** technology packages • is defined by the equation: $Powertrain\ Efficiency = \frac{Tractive\ Energy}{Fuel\ Energy}$

Table 4 Application of CO_2 Effectiveness and Powertrain Efficiency metrics in 'bottom-up' and 'top-down' approaches to estimating absolute CO_2 values of future tech packages

'bottom-up' approach	'top-down' approach
• applied by EPA in the 2016 PD as shown below • improvements measured incrementally, using ***CO_2 effectiveness*** • grounded in the requirement that EPA estimate the costs of adding technologies to achieve compliance. • ensures consistency between the estimated costs and future CO_2 improvements	• improvements measured using an absolute metric, ***powertrain efficiency*** • can be used as for quality assurance of 'bottom-up' approach • applied by Novation for the September 21st meeting as a quality assurance check of EPA's future CO2 values in the 2016 PD



In Section 1 above, EPA established that the incremental percentage reductions in CO_2 emissions for published ALPHA results are represented by LPM/OMEGA process without bias. The differences in efficiency and CO_2 identified by Novation at the September 21st meeting are therefore attributable to differences that lie outside of EPA's determination of incremental effectiveness. For this memo, EPA examined a range of possible explanations for the Novation-reported bias in LPM/OMEGA CO_2 values as illustrated in Figure 6 by quantifying the effect of:

1) differences in the content of technology packages being compared;
2) differences between a 0-D model and the published ALPHA runs for Exemplar vehicles;
3) differences in how a 0-D model and LPM/OMEGA adjust ALPHA Exemplar vehicle results when applying effectiveness to specific vehicles;
4) sensitivity of a 0-D model to the uncertainties in estimating tractive energy;
5) appropriateness of using published LPM effectiveness calibration ALPHA runs to represent absolute CO_2 values in a 0-D model

6) the degree to which the technology and road load characterization of the baseline fleet is aligned with the actual vehicles, as certified.

In the remainder of this section, EPA discusses each of these factors and summarizes findings from an investigation of each of these possible causes.

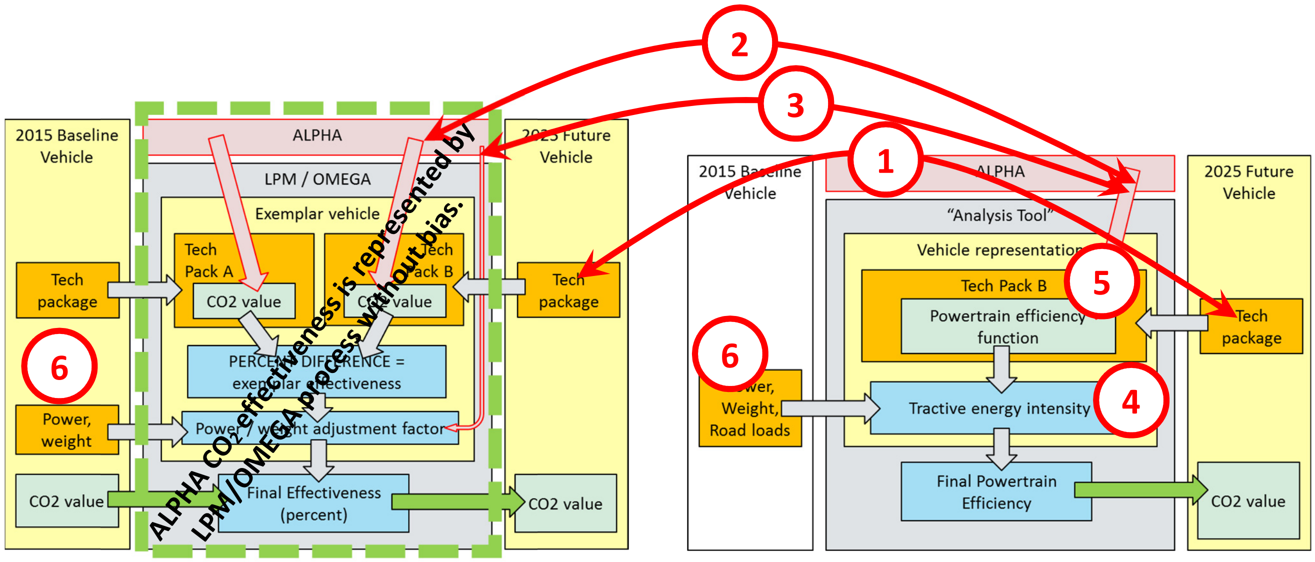


Figure 6 Areas in the approaches of EPA (left) and Novation (right) where differences might contribute to the Novation-reported bias in LPM/OMEGA CO_2 values

Overview of EPA's Alternate 0-D model of ALPHA and approach for investigating reported bias

A vehicle simulation model like ALPHA can be described as a 1-D simulation, where emissions, fuel consumption, and energy balances are evaluated in increments over the relevant test cycles along the time dimension. For computational efficiency, 1-D models can be used to calibrate 0-D models that eliminate the need to run time-based simulations for every vehicle and each possible technology combination. EPA's Lumped Parameter Model is one such 0-D model. In preparation for the September 21st meeting, Novation constructed another form of a 0-D model for the purpose of generating "vehicle-level CO_2 estimates based directly on the published ALPHA simulations, bypassing the LPM process" by using the tractive and fuel energy values provided in the 2016 PD LPM calibration ALPHA runs published by EPA. While this "Alternate 0-D" model was described by Novation in their presentation, EPA does not have the full details of the model specification, or the details regarding Novation's vehicle-level characterization of the LPM/OMEGA fleets, including both the MY2015 baseline and the MY2025 control case.[6] Therefore, to evaluate the existence and possible causes of any average

[6] In particular, EPA does not have model coefficients used by Novation, or the full details of Novation's assumptions and calculations for vehicle-level tractive energy intensities and engine displacements in the MYs 2015 and 2025 fleets. Note that for the 2016 PD, EPA published the vehicle-level specifications of the MY2015 baseline fleet which included test weight, road load coefficients, engine power and displacement, and tailpipe CO_2 emissions. For MY2025 LPM/OMEGA results, EPA published the platform-level percentage share of each technology package and CO_2. Vehicle-level comparisons of MY2025 powertrain efficiencies like those presented by Novation require an estimation of tractive energy intensities, and additional assumptions beyond the relevant published assumptions used in the LPM/OMEGA process.

misalignment in CO_2 and powertrain efficiencies between ALPHA and LPM/OMEGA in MY2025 packages, EPA has prepared an analysis using similar methods to those employed by Novation. The EPA analysis uses only the information that was published with the 2016 PD so that stakeholders can replicate the analysis without requiring any additional ALPHA runs.[7]

The EPA Alternate 0-D model was created using the published ALPHA results from the Proposed Determination and the model form defined on slide 34 of the Novation presentation and shown in Equation 1. Independent linear regressions were applied to each unique combination of road load groups, transmissions, and engines, thus retaining the original resolution of the published ALPHA results and obtaining a good model fit for every regression (R^2 >0.98). The coefficients and other details of the model are presented in Appendix A. Along with the methodology and results described, the full 0-D model is provided in spreadsheet format as an attachment. Note that in addition to this displacement specific approach, EPA also constructed a power specific 0-D model which produced identical results. This details of the power specific model are provided in Appendix B.

Equation 1 $$DSFEI = \beta_0 + \beta_1 * DSTEI$$

Where DSFEI = displacement specific fuel energy intensity [MJ/km/L]
DSTEI = displacement specific tractive energy intensity [MJ/km/L]
β_0, β_1 = model coefficients determined by linear regression (see 0, Table 7)

Key takeaway: *In order to investigate and quantify any potential bias in LPM/OMEGA's generation of future CO_2 values from ALPHA results, EPA prepared an analysis using similar methods to those employed by Novation utilizing only the information that was published with the 2016 PD. The results can be replicated by other stakeholders without requiring any additional ALPHA runs or the details of Novation's 0-D model.*

Figure 7 shows the results of EPA's attempt at replicating the Novation analysis, as described in their September 21st presentation. While the magnitude of the difference is less than Novation reported (see Figure 7 inset), EPA finds that when analyzed using the approach employed by Novation, the ALPHA results used for LPM effectiveness calibration do appear to have higher CO_2 and lower powertrain efficiency values than the LPM/OMEGA output for naturally aspirated gasoline direct injected (SI, NA) and high compression ratio Atkinson cycle (SI, Atkinson 2.) The reason for this remaining discrepancy in CO_2 and powertrain efficiency between the LPM/OMEGA results and EPA's Alternate 0-D model is addressed in the discussion of Factor #5 below.

First, however, EPA investigated the differences between EPA's Alternate 0-D analysis and the findings presented by Novation, which are highlighted in Figure 7. These differences could be the result of one or more of four distinct factors which may differ between the analyses. These factors are addressed individually in the discussion of Factors #1 through #4 below.

[7] Note that the ALPHA model has the capability to model the CO_2 performance of emissions-reducing technologies for specific applications beyond the exemplar vehicles (see EPA's 2017 FD Response to Comments, pp. 21-24.) EPA has chosen to limit the methods used for this memo to those that are readily available to all stakeholders.

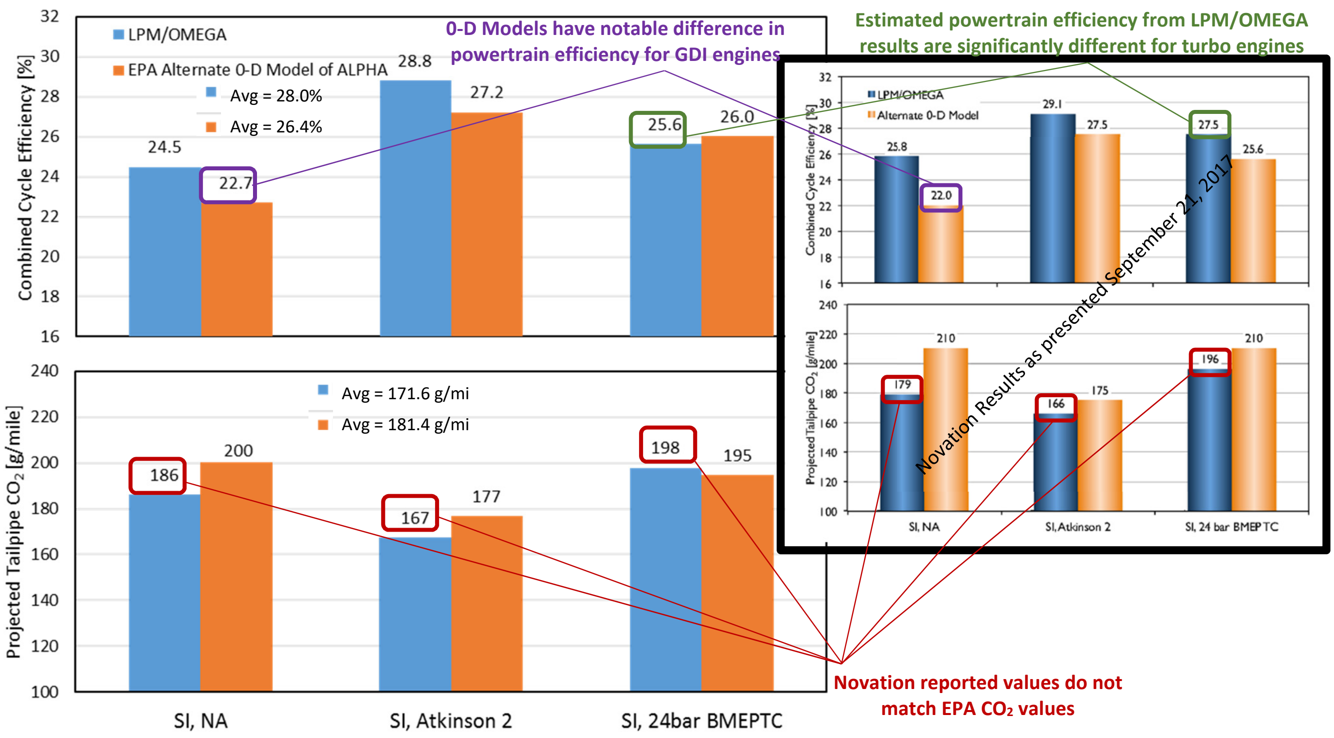


Figure 7 EPA Alternate 0-D Model of published ALPHA runs used for LPM calibration compared to LPM/OMEGA output for MY2025 (Novation results are in the inset)

Factor #1: Differences in the content of technology packages being compared

When assembling the data for Figure 7, EPA began by adjusting the technology package content of the LPM/OMEGA output to match technology packages in the published ALPHA results. This same process was used in EPA's re-evaluation of the alignment in LPM and ALPHA effectiveness values in Section 1, as summarized in Table 2. EPA then categorized engine and transmission technologies in the same way that Novation showed on Slide 14 of the September 21st presentation, to ensure that the average efficiencies and CO_2 values are comparable to Novation's results, and representative of the same group of vehicles. The results of EPA's classification in Table 5 below show that non-stop-start powertrains represented in the published ALPHA results make up 18 percent of MY2025 volume. This percentage, as well as the percentages for each individual technology group shown in Table 5 match the values on Slide 14 of Novation's presentation, indicating that EPA's classification of technologies is consistent with Novation's.

Table 5 Population of MY2025 vehicles in OMEGA output included in powertrain efficiency and CO2 comparisons (highlighted in green)

Powertrain Type	Engine Technology	EGR	Fuel System	Cyl. Deac.	Stop-Start	Trans.	Vol in MY 2025 OMEGA Fleet	% of MY 2025 OMEGA Fleet	ALPHA Simulations Available?	% of Vol represented in ALPHA Simulations
SI	Atkinson @ 13:1 CR		Direct	yes		ATX	207,082	1.3%		
SI	Atkinson @ 13:1 CR		Direct			ATX	120,105	0.7%	yes	**18.4%**
SI	Atkinson @ 14:1 CR	cooled	Direct	yes		ATX	2,320,610	14.1%	yes	
SI	24 bar BMEP TC	cooled	Direct			ATX	104,308	0.6%	yes	
SI	Nat. Asp.		Direct			ATX	480,510	2.9%	yes	
SI	Nat. Asp.		Direct	yes		ATX	92,803	0.6%		
SI	Nat. Asp.		Port			ATX	761,635	4.6%		
SI	Nat. Asp.	cooled	Port			ATX	401,629	2.4%		
SI	Nat. Asp.		Port	yes		ATX	2,189,458	13.3%		
SI	18 bar BMEP TC		Direct			ATX	3,115,138	19.0%		
SI	18 bar BMEP TC	cooled	Direct			ATX	16,866	0.1%		
SI	Atkinson @ 13:1 CR		Direct	yes	yes	ATX	113,516	0.7%		
SI	Atkinson @ 13:1 CR		Direct		yes	ATX	-	0.0%		**7.6%** (after removal of Stop-start benefit)
SI	Atkinson @ 14:1 CR	cooled	Direct	yes	yes	ATX	966,772	5.9%		
SI	24 bar BMEP TC	cooled	Direct		yes	ATX	243,259	1.5%		
SI	Nat. Asp.		Direct		yes	ATX	43,325	0.3%		
SI	Nat. Asp.		Direct	yes	yes	ATX	158,803	1.0%		
SI	Nat. Asp.		Port		yes	ATX	-	0.0%		
SI	Nat. Asp.	cooled	Port		yes	ATX	41,953	0.3%		
SI	Nat. Asp.		Port	yes	yes	ATX	260,640	1.6%		
SI	18 bar BMEP TC		Direct		yes	ATX	655,011	4.0%		
SI	18 bar BMEP TC	cooled	Direct		yes	ATX	-	0.0%		
SI	18 bar BMEP TC		Direct	yes	yes	ATX	643	0.0%		
SI	18 bar BMEP TC	cooled	Direct	yes	yes	ATX	-	0.0%		
SI	Miller Cycle	cooled	Direct	yes	yes	ATX	37,679	0.2%		
SI-E	Mild Hybrid						3,031,771	18.5%		
SI-E	Strong Hybrid						360,942	2.2%		
PHEV							80,085	4.2%		
EV							276,798			
SI,MT							337,512			
Total							**16,418,850**	**100.0%**		

EPA evaluated the potential effect of a misalignment between the LPM/OMEGA and ALPHA technology packages used in the analysis by not removing the CO_2 benefits of the technologies which are included in LPM/OMEGA output, but not included in the published ALPHA runs. Those technologies are listed in Table 2. The results in Figure 8 show that when using these "misaligned" technology packages, the LPM/OMEGA CO_2 values match the values presented by Novation. Compared to the correctly aligned packages in Figure 7, the LPM/OMEGA CO_2 values in Figure 8 are 1 to 2 g/mi higher for the SI, Atkinson 2 and SI, 24bar BMEPTC groups, and 7 g/mi higher for the SI,NA group. Overall, the effect of not aligning technology package content with the published ALPHA results causes the LPM/OMEGA output CO_2 values to appear to be lower by an average of 2.4g/mi for the population of vehicles considered in Novation's analysis.

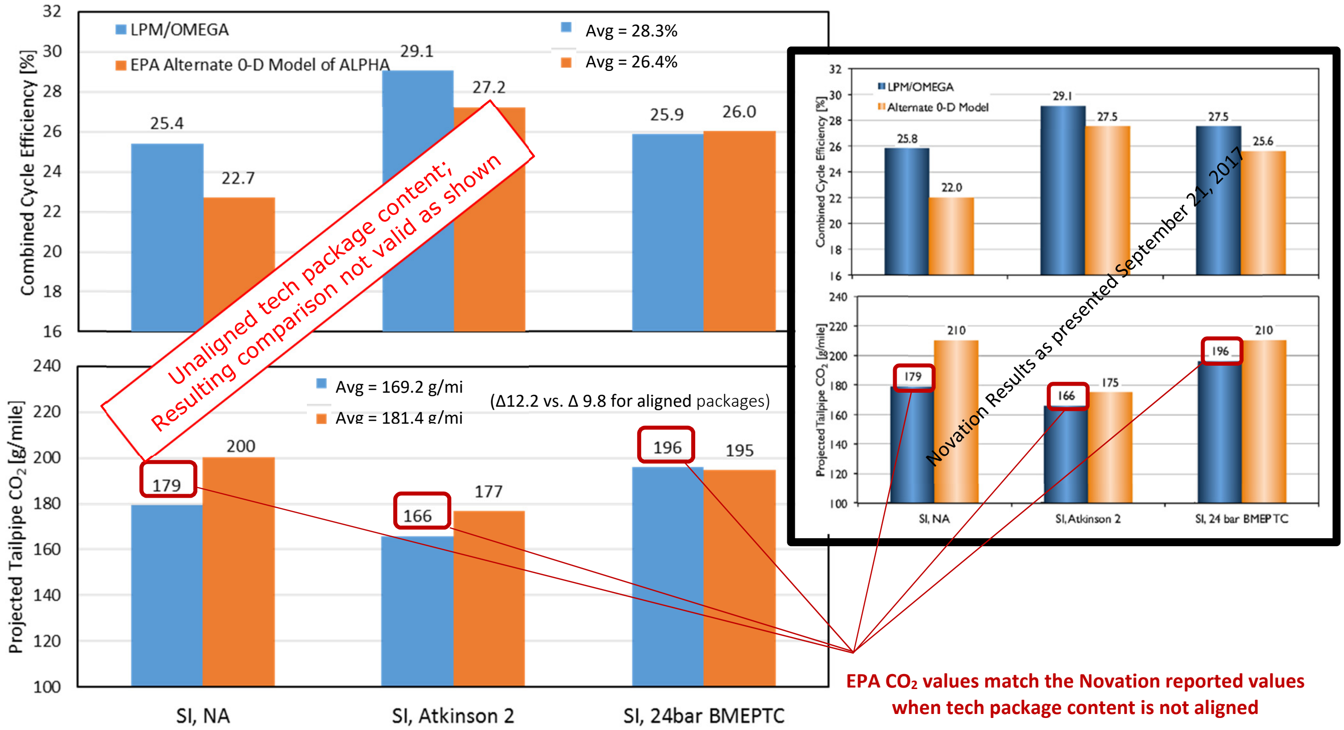


Figure 8 Effect of not aligning technology package content between published ALPHA runs used for LPM calibration and LPM/OMEGA output

Key takeaway: *The effect of not aligning technology package content with the published ALPHA results causes the LPM/OMEGA output CO_2 values to appear to be lower by an average of 2.4g/mi for the population of vehicles considered in Novation's analysis.*

Factor #2: Differences between a 0-D model and the published ALPHA runs for exemplar vehicles

As described in Appendix A, the EPA 0-D model was generated by applying linear regressions to the published ALPHA results for each distinct combination of engine, transmission, and road load group. Figure 9 shows that the 0-D model has good correlation with the published ALPHA runs for the exemplar vehicles, both in terms of tailpipe CO_2 values and CO_2 effectiveness. Specifically, CO_2 values of the 0-D model are within ±4g/mi of the ALPHA exemplar vehicles, and +4 g/mi and MY2025 weighted average CO_2 values are within 1 g/mi (with the EPA 0-D model value 0.7 g/mi higher.)

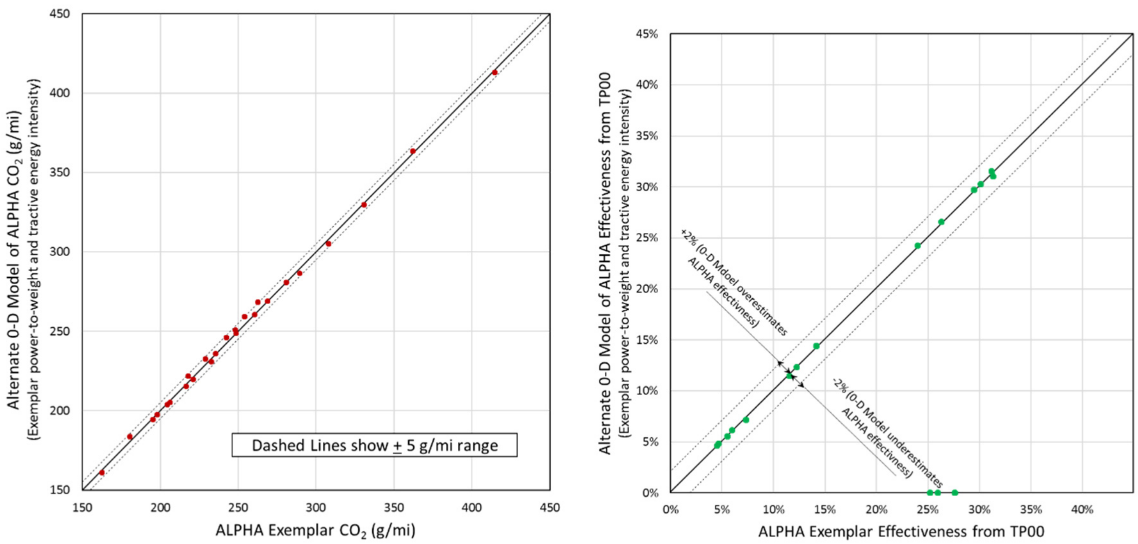


Figure 9 Correlation of EPA's Alternate 0-D model of ALPHA (y-axes) with published ALPHA exemplar runs (x-axes) for tailpipe CO_2 (left) and CO2 effectiveness (right)

While EPA does not have the full details of the 0-D model used by Novation, the September 21st presentation describes a model specification which departs in several ways from a full resolution representation of the published ALPHA runs. First, the Novation model is described as applying power-to-weight multipliers for performance neutrality by only distinguishing between two transmission types (TRX1 and TRX2) rather than the three different transmission types (TRX11, TRX21, and TRX22) as EPA's 0-D model does. The aggregation of TRX21 and TRX22 into a single transmission type would tend to cause a 0-D model to overestimate the emissions of the more efficient TRX22 transmission, and underestimate the emissions of the less efficient TRX21 transmission, as illustrated in Figure 19 of Appendix A.

The second way in which the 0-D model described by Novation departs from a full-resolution representation of the published ALPHA results is by aggregating all six ALPHA classes into a single regression. As shown in Figure 18 of Appendix A, the three ALPHA classes with higher road loads (LPW_HRL, MPW_HRL, and Truck) demonstrate a somewhat different relationship between DSTEI and DSFEI than the lower load ALPHA classes (LPW_LRL, MPW_LRL, HPW.) The result of an unnecessary aggregation of all six ALPHA classes will cause a 0-D model to tend to underestimate the emissions of the low road load classes and overestimate the emissions of the high road load classes.

EPA evaluated the effect of additional aggregation of the published ALPHA results by creating a 'low-resolution' version of the 0-D model. The resulting CO_2 and effectiveness values presented in Figure 10 confirm that the low-resolution model tends to overestimate emissions (and underestimate effectiveness) of packages containing the TRX22 transmission, and underestimate emissions (overestimate effectiveness) of packages containing the TRX21 transmission. Because the MY2025 fleet contains more packages with TRX22 transmissions than with TRX21 transmissions, the net effect of the low-resolution 0-D model is to cause the average CO_2 emissions to increase by 2.2 g/mi, to 183.6 g/mi as shown in Figure 11, compared to the average of 181.4 g/mi in Figure 7. The average powertrain efficiency for SI, NA engines in the low-resolution 0-D model is 22.0 percent, matching the efficiency presented by Novation, which is notable since that group of vehicles is comprised entirely vehicles that started with TRX21 transmissions in the MY2015 baseline, and had TRX22 transmissions applied in MY2025. The combined effects of Factor #1 (misaligned technology packages) and Factor #2 (the low-resolution 0-D model) are shown in Figure 12.

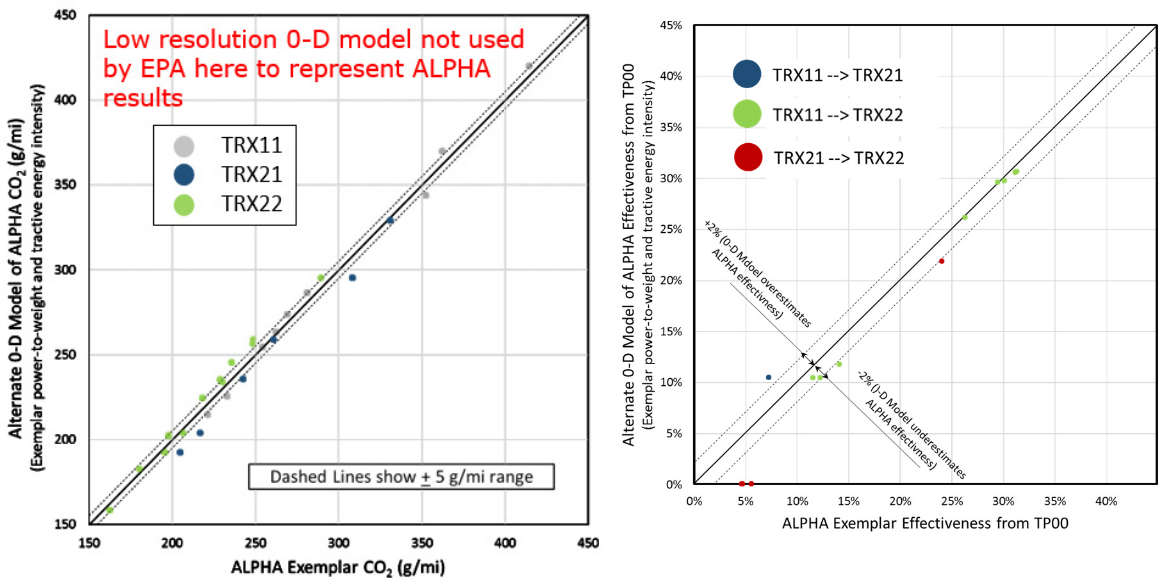


Figure 10 Correlation of Low Resolution 0-D model of ALPHA (y-axes) with published ALPHA exemplar runs (x-axes) for tailpipe CO_2 (left) and CO2 effectiveness (right)

Figure 11 Effect of low-resolution 0-D model of published ALPHA runs used for LPM calibration and LPM/OMEGA output

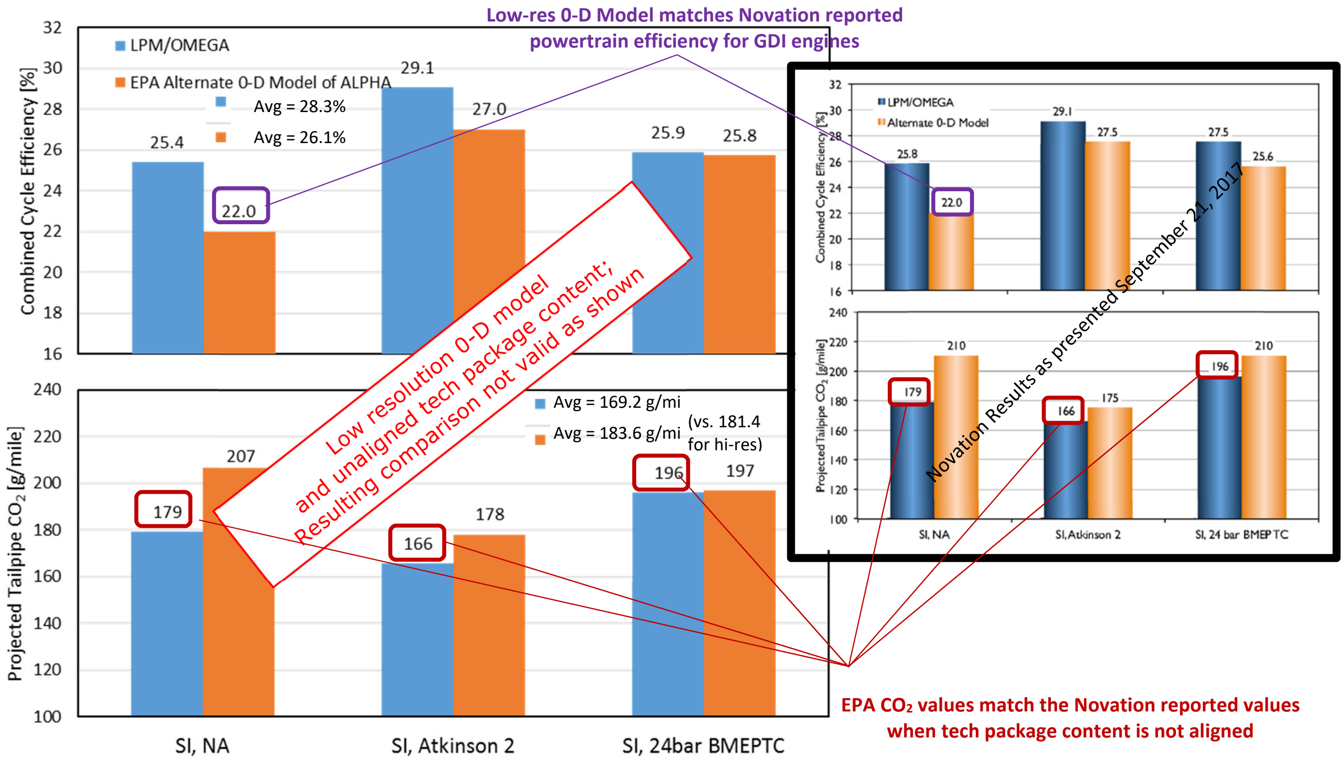


Figure 12 Combined effects of misaligned technology packages and low-resolution 0-D model

Key takeaway: *The effect of the use of a low-resolution 0-D model of published ALPHA results causes the output CO_2 values to appear to be higher by an average of 2.2 g/mi for the population of vehicles considered in Novation's analysis.*

Factor #3: Differences in how 0-D model and LPM/OMEGA adjust ALPHA exemplar vehicle results when applying to specific vehicles

The procedure used in EPA's LPM/OMEGA model for applying technology effectiveness improvements involved adjusting the exemplar vehicle effectiveness values based on the power-to-weight differences between individual vehicles and the exemplars. These effectiveness adjustments were developed using ALPHA power-to-weight sweeps for various technology groups as described in Section 2.3.3.5.4 of the PD TSD, which includes the adjustment values used in Table 2.55. The 0-D model described by Novation in the September meeting uses a different approach for applying exemplar vehicle results to individual vehicles. Instead of an explicit power-to-weight adjustment, CO_2 values are calculated as a function of displacement specific tractive energy, so that the accounting of differences between specific vehicles and the exemplars is inherent in the regressions.

One of Novation's conclusions at the September meeting was that "EPA's use of power-to-weight ratio is not a robust surrogate for brake mean effective pressure." In place of power-to-weight ratio, Novation recommended that EPA consider the use of alternate 0-D models based on displacement-specific energy. For this section, in order to evaluate how the difference in approaches used to quantify vehicle load (displacement specific tractive energy versus power-to-weight) might contribute to the difference between ALPHA and LPM/OMEGA results reported by Novation, EPA created an additional 0-D model with a power specific basis, rather than a displacement specific basis. The power specific 0-D model is described in more detail in Appendix B.

The displacement specific model described by Novation maintains performance neutrality when applying technology packages by holding the power-to-weight of individual vehicles constant. Displacement is then a function of the estimated values for power (hp), and for power density (hp/L) which is assumed to be constant within technology groups. As long as vehicle weight values and corresponding tractive energies are consistent between the two models, the perfect correlation between the displacement specific and power specific models shown in Figure 14 is an expected finding, and a trivial one, given the mathematical relationship between the two models. A more detailed discussion the use of power-to-weight ratios and displacement specific tractive energy is provided in Section 3.

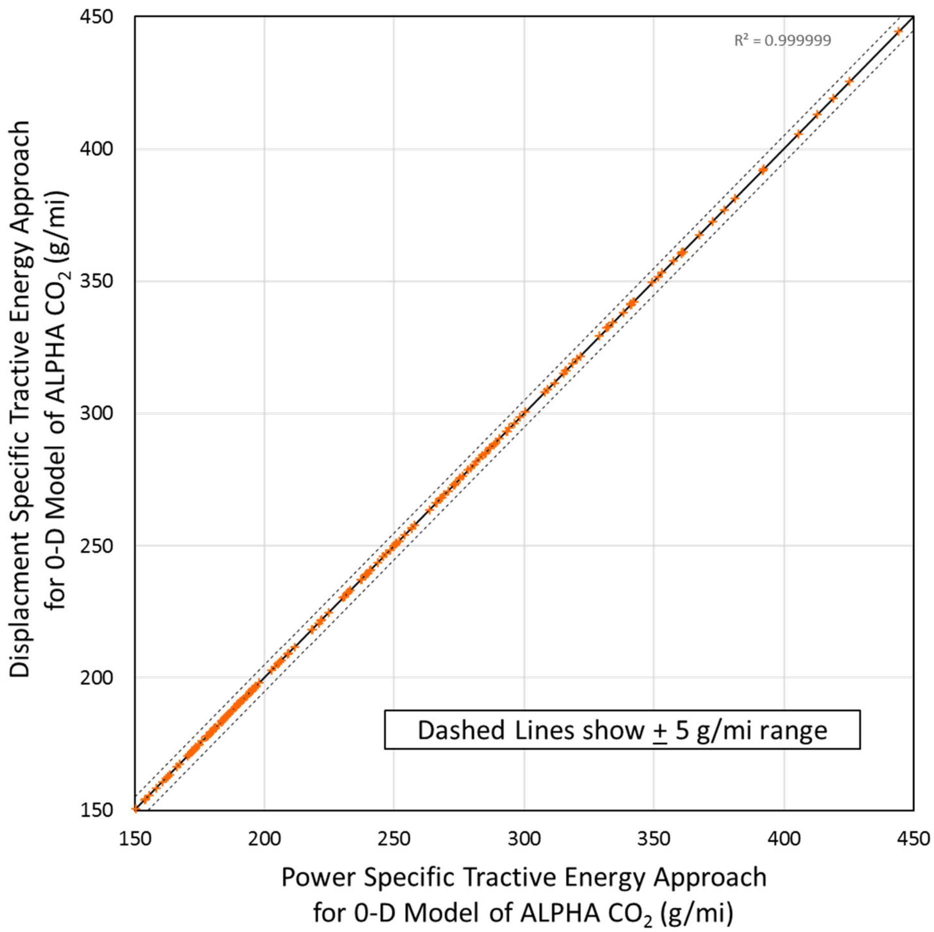


Figure 13 Correlation between displacement specific and power specific 0-D models

Key takeaway: *A displacement specific model which maintains performance neutrality by maintaining power-to-weight ratios is mathematically identical to a power specific model.*

A full consideration of the appropriateness of applying ALPHA CO_2 results to specific vehicles in the fleet involves more than a top-down efficiency analysis and comparison of power normalization and displacement normalization methodologies. The full scope on a vehicle-by-vehicle basis is not possible to ascertain without running additional ALPHA runs for individual vehicles as was done in EPA's original creation of Figure 2.100, and in EPA's ongoing work. EPA has limited the analysis here to lie within scope of this memo, which is to examine the purported difference between ALPHA and the LPM/OMEGA CO_2 values using the methodologies described by Novation.

Factor #4: Sensitivity to the uncertainties in estimating tractive energy

One of the characteristics of the 0-D model described by Novation at the September meeting is the dependency of the model output on estimates of tractive energy intensity. In this model form, any uncertainties and errors in the tractive energy estimate will translate proportionally into variation in fuel energy intensity and CO_2 as can be seen in Equation 1.

Novation did not provide details for the tractive energy estimates used in the September presentation, but it is evident that Novation and EPA assumed different tractive energies for MY2025 vehicles, since as shown in Figure 8, the LPM/OMEGA CO_2 values are the same for unaligned packages in the EPA and Novation charts, but the LPM/OMEGA powertrain efficiencies are different. Since the technology penetrations in Table 5 indicate that EPA and Novation are using the same subpopulation of vehicles, the difference in powertrain efficiency could only the result of differences in how EPA and Novation estimated tractive energy intensities for these vehicles.

In the absence of details about the specific approach used by Novation, EPA evaluated several different methods of estimating future road load coefficients, given a defined combination of percentage mass, aerodynamic, and tire rolling resistance reductions. The results of one of these variants are shown in Figure 14, where the target A coefficent for MY2025 vehicles with advanced technology packages was kept unchanged from TP00. While this is not likely the same approach that was used by Novation, the newly estimated road load coefficients result in an average powertrain efficiency that is similar to the 27.5 percent value reported by Novation for these 13 turbocharged vehicle models. If we assume that Novation applied the same tractive energy values when calculating powertrain efficiencies for both the LPM/OMEGA and 0-D models, then the sensitivity of the 0-D model CO_2 values to variation on tractive energy estimates can be estimated. For the subpopulation of vehicles included in the Novation analysis, applying the average tractive energies that would produce the Novation-reported LPM/OMEGA powertrain efficiencies to the Alternate 0-D model would result in an increase of 0.5 g/mi in the average estimated CO_2 value from the 0-D model.

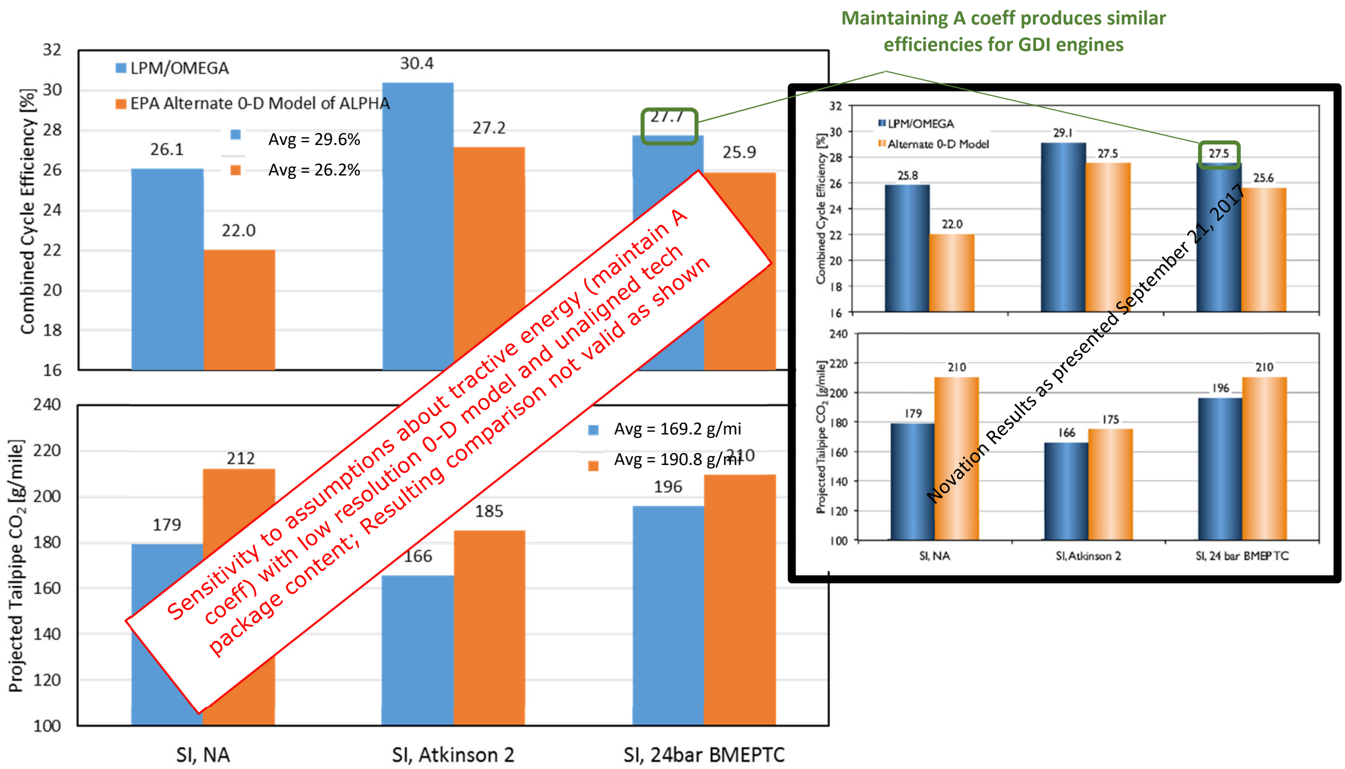


Figure 14 Effect of changing the road load coefficient adjustments (example shown where A coefficient is maintained)

Key takeaway: *Applying the average tractive energies that would produce the Novation-reported LPM/OMEGA powertrain efficiencies to the Alternate 0-D model would result in an increase of 0.5 g/mi in the average estimated CO_2.*

Factor #5: Appropriateness of using published ALPHA runs for LPM effectiveness calibration to represent absolute CO_2 values: The effect of double counting transmission neutral drag losses

As noted earlier, EPA uses the ALPHA model to develop CO_2 effectiveness values to represent the incremental benefit of future technologies. In the 2016 PD, and previous compliance analyses, EPA did not intend for the ALPHA results to represent the absolute CO_2 performance of actual vehicles. One previous exception, for the 2017 Final Determination, detailed ‘technology walks’ that EPA conducted for specific vehicles using ALPHA. From the Final Determination Response to Comments document (pg 23):

> *“due to a number of conservative assumptions made when conducting this technology walk analysis, the opportunity for conventional technologies to contribute to achieving the standards will likely be even greater than indicated by these results. The first of these conservative assumptions is the effective double counting of transmission neutral-drag losses. Specifically, since EPA had not quantified these losses for each specific vehicle, the road load coefficients were not adjusted, resulting in an average 3 percent greater CO_2 value for the 10 modeled baseline vehicles than the actual tested vehicles; an overestimation that is likely propagated to some extent through the subsequent technology packages in each techwalk.”*

The ALPHA full-vehicle simulations at the time effectively double-counted neutral-drag losses in the vehicle. ALPHA uses the coast down coefficients to determine the road load applied to the vehicle; the magnitude of these coefficients include the spin losses associated with the differential and with the portion of the transmission connected to the wheels during a neutral coast down. ALPHA also includes a separate transmission model which incorporates the same losses, and thus they are effectively double-counted during the simulation.

EPA has not quantified the magnitude of these double-counted transmission and drivetrain losses for each vehicle in the fleet, and for the PD analysis, EPA chose to maintain the double-count within the ALPHA simulations. Although the resulting CO_2 values modeled by ALPHA would be consistently higher due to the additional double-counted losses, the *effectiveness* calculated from the resulting percent decrease in CO_2 would consistently be slightly lower than otherwise. This is because the additional CO_2 associated with the transmission spin losses is carried through the analysis as a portion of the coast down coefficients. In future, lower CO_2 packages, the additional CO2 becomes a larger percentage of the final CO_2 calculation. Since EPA analysis is based on effectiveness rather than absolute CO_2, the slight conservative bias in the analysis was deemed preferable.

However, in their presentation, Novation has focused on the absolute CO_2 results from ALPHA. Thus, to estimate the effect of the transmission double-count on the final CO_2, EPA attempted to estimate the magnitude of the portion of the coast down road load which was created by the transmission neutral spin losses. EPA used the test car list to determine A, B, and C vehicle coefficients (i.e., the difference between target coefficients and set coefficients) for vehicles in the fleet. Assuming that the tire losses were primarily confined to the A coefficient, the remaining vehicle B and C coefficients were assumed to be a function of the transmission and drivetrain spin losses, along with a portion of the A coefficient (based on a fleet average manual transmission, the slope of the quadratic, and the vehicle size). The final calculations for the transmission double-count were:

- Ctrans = Cvehicle = Ctarget – Cset
- Btrans = Bvehicle = Btarget – Bset
- Atrans = -22*Btrans + 5.3*(RL@50mph/18)

Where the (RL@50mph/18) is a normalizing factor that scales the resulting A coefficent with vehicle size. When the result from this methodology are compared to transmission loss data measured on a set of real transmissions, the match is reasonably close.

This estimation methodology was used to modify the coast down coefficients within ALPHA for a set of vehicles representing the fleet. The vehicles were simulated in ALPHA with the original coast down coefficients, and again with modified coast down coefficients. This resulted in a reduction in CO_2 grams/mile of between 2.5% and 5.0% for nearly all vehicles, and about 4% on average.

The results of accounting for the double counting of transmission neutral drag losses with the low-resolution 0-D model and without aligning technology packages are shown in Figure 15.

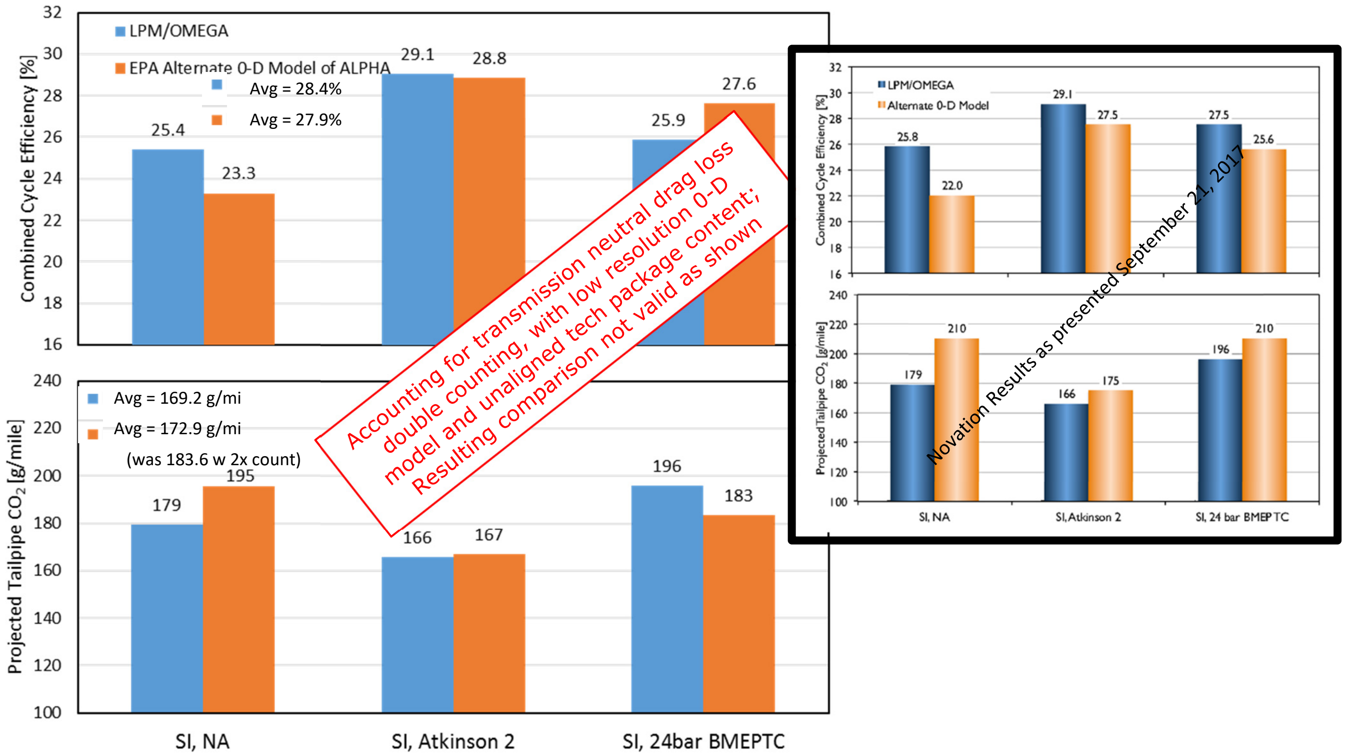


Figure 15 Effect of removing transmission drag loss double-counting with misaligned technology packages and low-resolution 0-D model

> ***Key takeaway:*** *The published ALPHA results were used for the calibration of CO_2 effectiveness values in the LPM for the 2016 PD, and were not intended to represent the absolute CO_2 performance of actual vehicles.*

Factor #6: Alignment of technologies and road load characterization of the baseline fleet to actual vehicles

Because EPA's analysis for the PD relies on effectiveness, or the percent reduction in CO_2, the final fleet CO_2 numbers, and the inferred powertrain efficiencies, rely on the characterization of the baseline fleet. This characterization includes both an assessment of the technology packages within the vehicle, and the application of appropriate road load values to all vehicles. Misalignments of either may cause final CO_2 numbers, and associated powertrain efficiencies, to vary in either direction.

A study of this variation would require substantial assumptions about the baseline fleet and the accuracy of its characterization, and is beyond the scope of this memo. However, EPA is studying how to improve characterization of the baseline, and potentially quantify the effect of any misalignment.

Most representative assessment of the alignment between LPM/OMEGA and ALPHA

When the previous factors are accounted for as completely as possible, the comparison between the 0-D ALPHA model and the LPM/OMEGA outputs are shown in Figure 16. These results show a much closer correlation between the two, and in fact show the LPM as having slightly higher CO_2 values (i.e., conservative) compared to the ALPHA 0-D model.

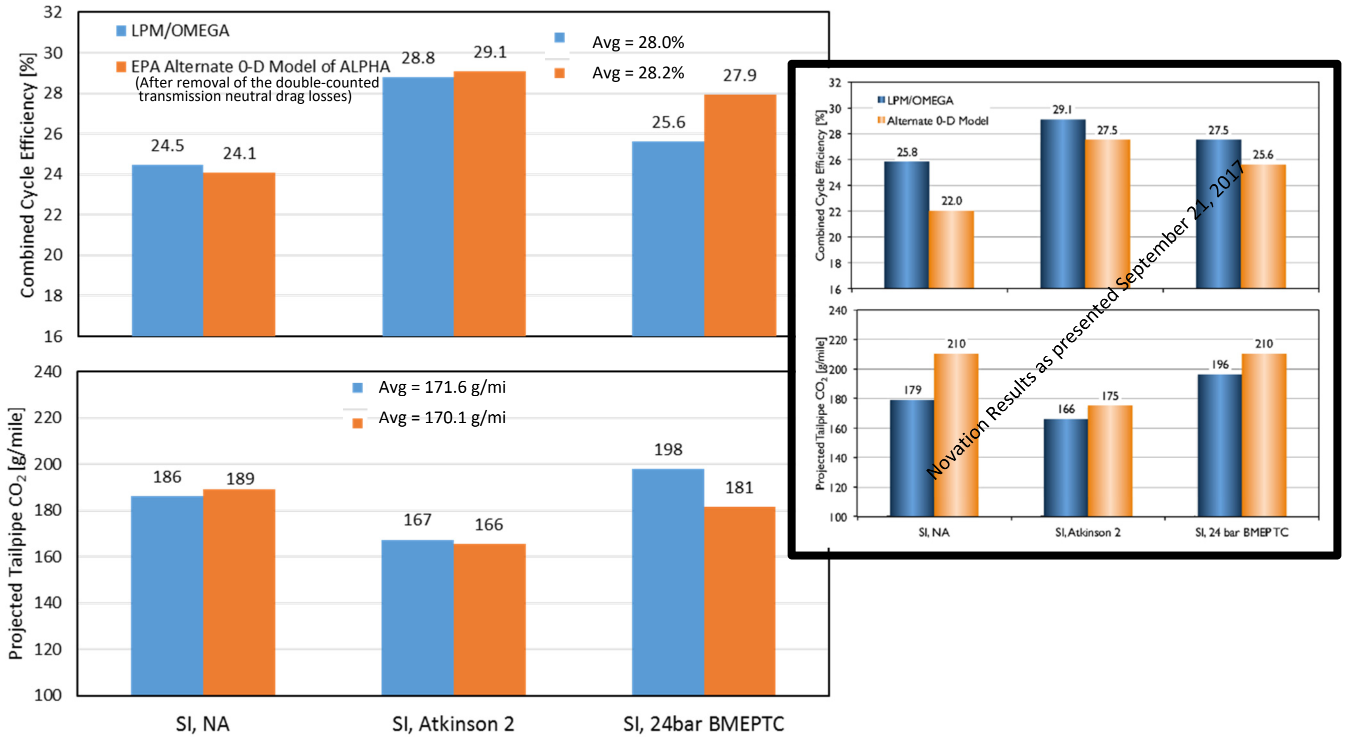


Figure 16 Most representative comparison of EPA Alternate 0-D Model of published ALPHA runs to LPM/OMEGA output (Novation results in inset)

Table 6 Average CO_2 and Powertrain Efficiency for the most representative comparison of EPA Alternate 0-D Model of published ALPHA runs to LPM/OMEGA output

	EPA Alt 0-D Model[*1]	LPM/OMEGA	Delta (LPM minus 0-D)
CO_2	170.1 g/mi	171.6 g/mi	1.5 g/mi
Powertrain Efficiency	28.2%	28.0%	0.2%

[*1] After removal of the double-counted transmission neutral drag losses

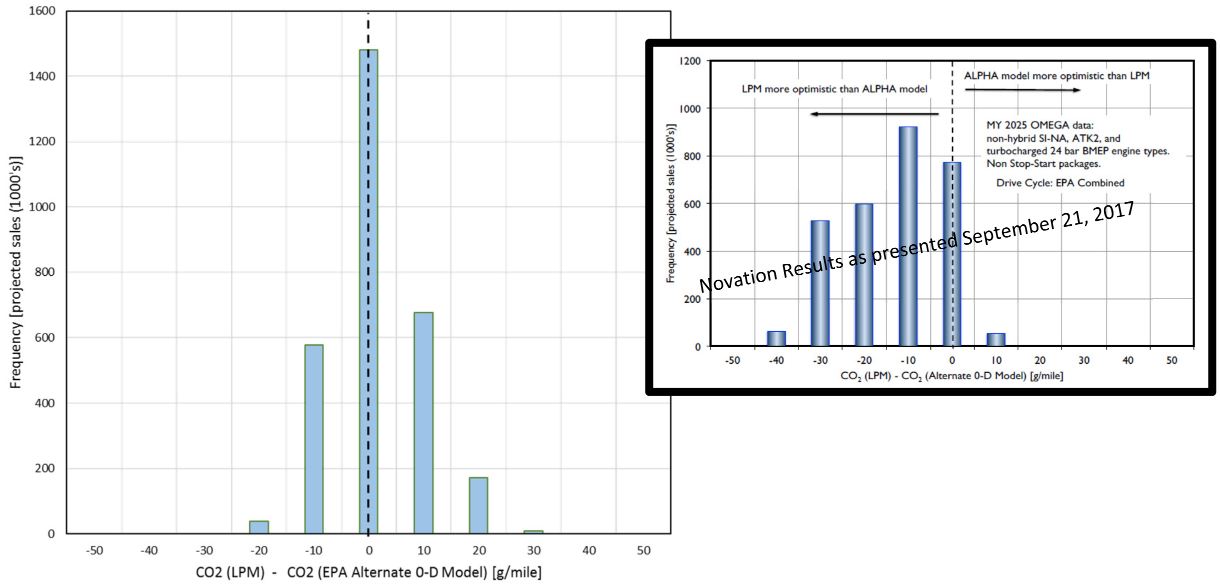


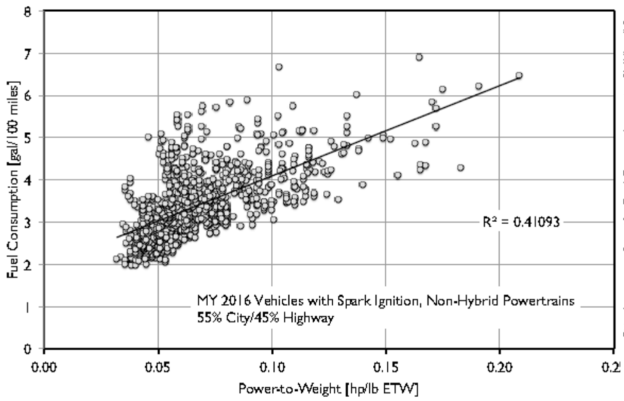
Figure 17 Most representative comparison of EPA Alternate 0-D Model of published ALPHA runs to LPM/OMEGA output (Novation results in inset)

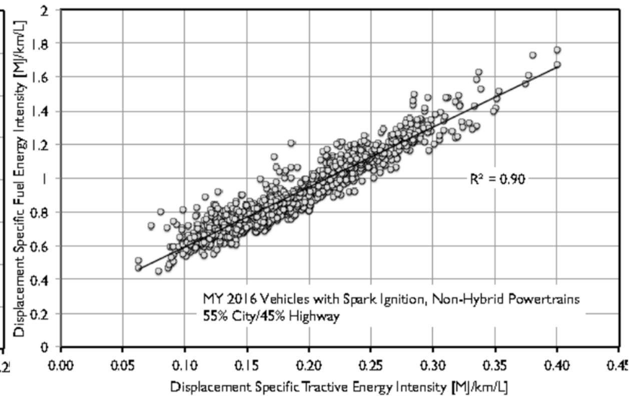
Key Takeaway: *After accounting for Factors #1 to #6, LPM CO_2 values are within 2 g/mi (1.5g/mi higher than) the CO_2 values estimated by EPA's Alternate 0-D model of the published ALPHA results.*

3. Power-to-Weight ratio vs. Displacement-specific energy

In Novation's presentation, they conclude that "EPA's use of power-to-weight ratio is not a robust surrogate for brake mean effective pressure. Additionally, its sub-classification (power-to-weight ratio and road load bins) provides little benefit." This conclusion is based on a portion of Novation's analysis which focuses on EPA's use of power-to-weight ratio as compared to Novation's preferred displacement-specific energy. However, although Novation has some specific suggestions that are warranted, their key conclusions are unsupported, as this section will show.

Specifically, Novation contrasted two figures, the first showing fuel consumption correlated with power-to-weight ratio, and the second showing displacement-specific fuel consumption correlated with displacement-specific tractive energy. The contrast between the two figures was intended to illustrate the difference between EPA's methodology and Novation's methodology. These two figures are reproduced below.





Novation examined the correlations shown in the two figures, and stated that "Power-to-weight accounts for only 41% of the variation in fuel consumption (and CO_2 emissions) across the vehicle fleet." (from the first figure), while "displacement-specific fuel consumption is linearly correlated to displacement specific load and accounts for 90% of the variation in fuel consumption across the vehicle fleet." (from the second figure). The contrast between the two figures leads to the "key takeaway" that "Displacement specific energy domain provides a significantly higher correlation than power-to-weight ratio."

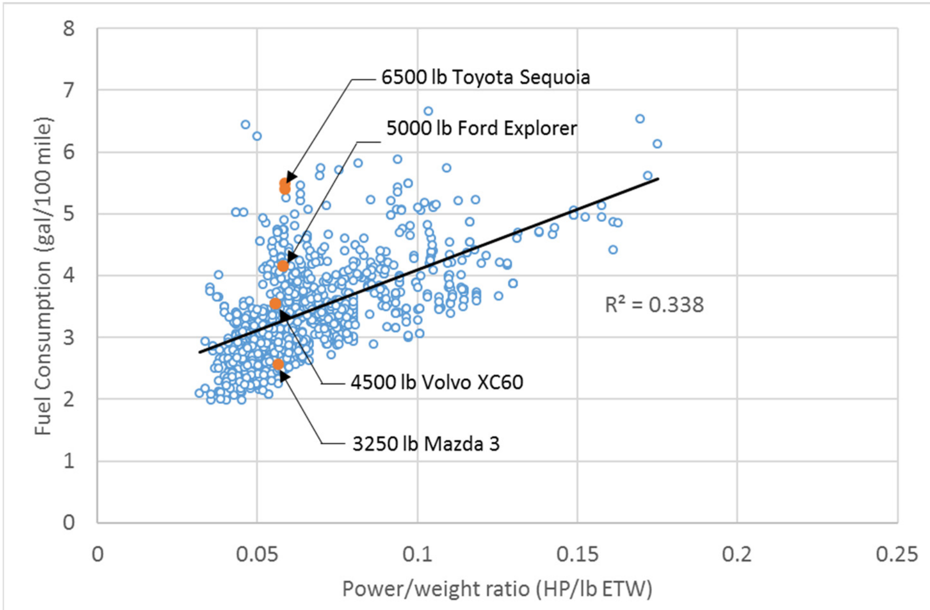
However, the "key takeaway" is based on conflating the effect of one parameter on the correlation with the effect of another. There are, in fact, three fundamental differences between the two figures:

1) the use of displacement rather than power as a normalizing factor.
2) the use of tractive energy versus weight as a representation of vehicle loading.
3) the use of a normalizing factor for fuel consumption (the y-axis).

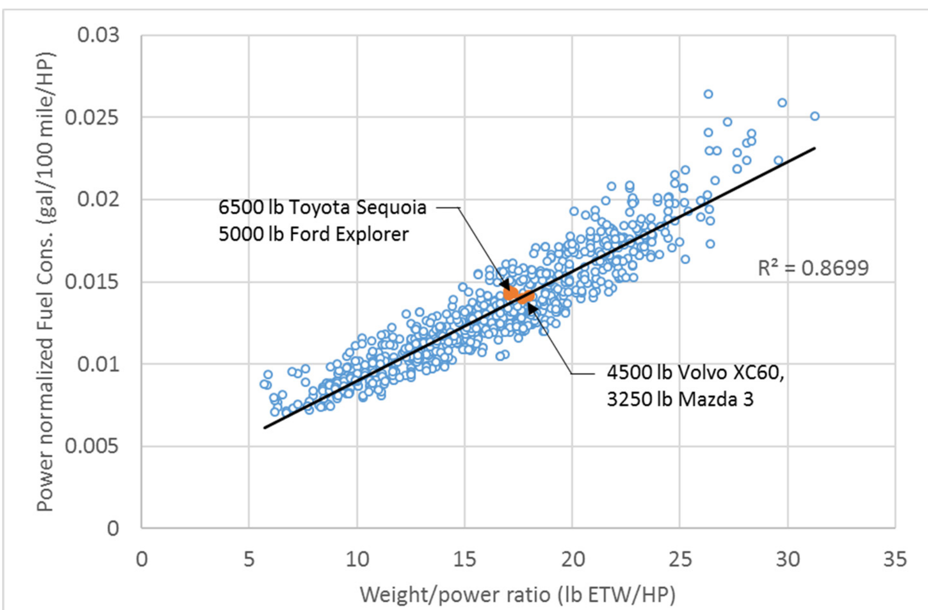
Novation points to the first (and to some extent the second) difference, implying that the use of power rather than displacement is the source of the correlation differences. However, the last difference, the use of a y-axis normalization factor, is most important.

Normalizing fuel consumption

When EPA calculates adjustment factors based on the power/weight ratio, the adjustment factors represent a change in effectiveness, which adjusts the CO_2 value by a percentage, not by an absolute amount. Novation's use, in their analysis, of absolute fuel consumption in gallons/mile incorrectly implies that all vehicles with the same power/weight ratio will receive the same absolute CO_2 adjustment. As an example, EPA reproduced a version of Novation's fuel consumption-power/weight ratio graph (shown below), labeling some specific vehicles. These four vehicles – a 6500 pound Toyota Sequoia, a 5000 pound Ford Explorer, a 4500 pound Volvo XC60, and a 3250 pound Mazda3 – have nearly the same power/weight ratio, but different engine power and ETW.



A representation that would be more reflective of EPA's process would be to normalize the fuel consumption by an engine scaling factor. Novation has chosen to use engine displacement in their displacement-specific fuel consumption, which is a reasonable methodology. To contrast, EPA normalized the fuel consumption by the engine power, as well as inverting power/weight ratio to linearize the resulting graph (shown below). After normalization, the result is that the correlation between power-normalized fuel consumption and weight/power accounts for 87% of the variation in fuel consumption.

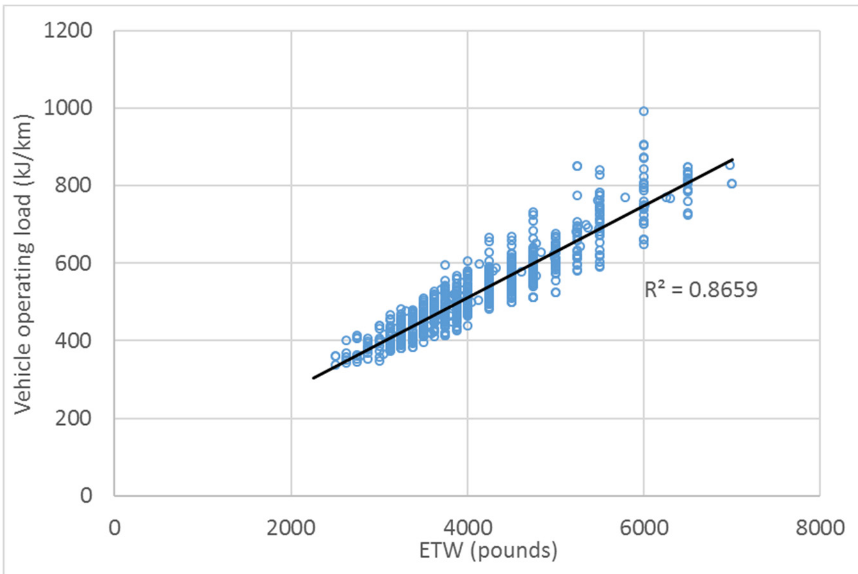


Here, the four vehicles mentioned in the example have nearly the same weight/power ratio, and nearly the same normalized fuel consumption. Any percentage adjustment based on the vehicles' power/weight ratio would adjust each vehicle's CO_2 similarly, <u>as a percentage</u>.

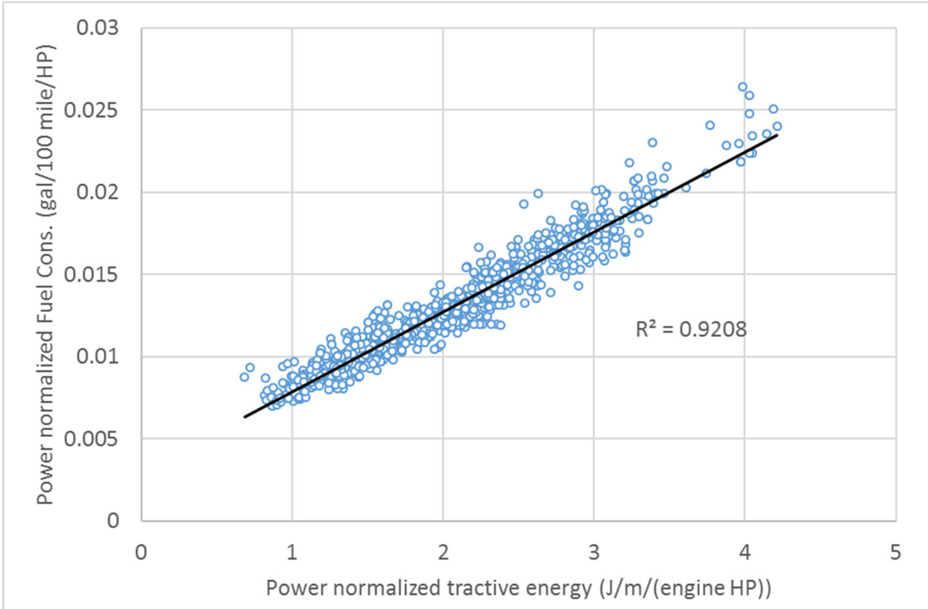
Key takeaway: *Normalization of fuel consumption, not use of displacement specific energy, is the most significant factor in the correlation of load and fuel consumption.*

Use of tractive energy

The correlation between weight/power ratio and normalized fuel consumption is 87%, not quite as high as Novation's 90% correlation when using displacement specific tractive energy. Novation correctly points out that weight does not fully capture tractive energy – the effect of other road loads, represented by the coast-down coefficients, is not directly captured by the use of only weight. Weight is correlated with road load horsepower, and thus with the total vehicle operating load, but will only account for 86% of the vehicle tractive energy, as shown below.



The effect of substituting tractive energy for only weight can be shown by using a "power normalized" tractive energy metric, as shown below.

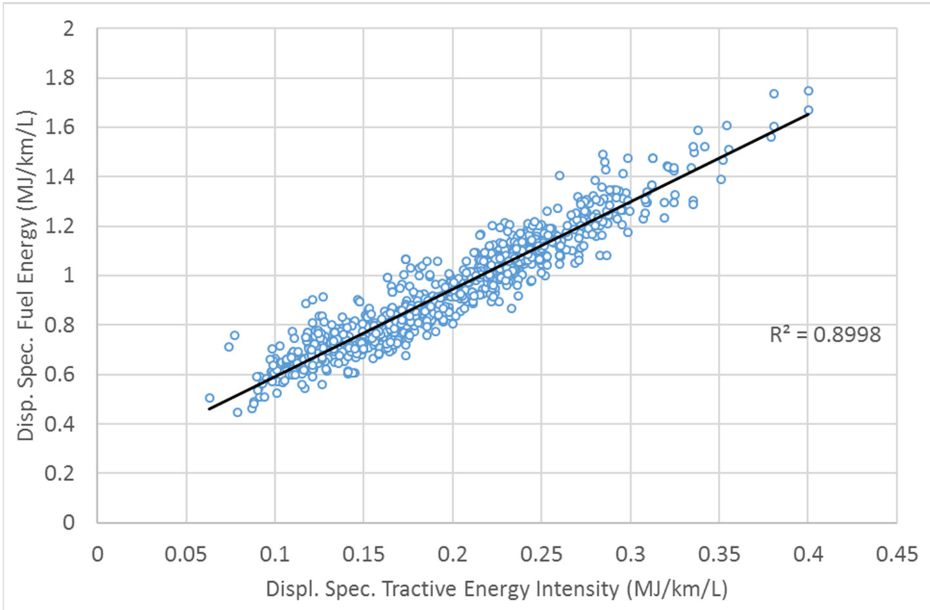


In this case, the correlation is noticeably better, at 92%. EPA believes using tractive energy, or another metric that includes the effects of road loading as well as vehicle weight, represents a more robust methodology, and is preparing to implement this effect in their modeling process.

Key takeaway: *The use of tractive energy is more robust than the use of only weight to represent load.*

Use of displacement for normalization

Finally, displacement can be used rather than power as a normalization metric, as suggested by Novation. Implementing this change (and converting units, which has no effect on the correlation) produces the figure below, which is substantially similar to Novation's figure, and has the same 90% correlation.



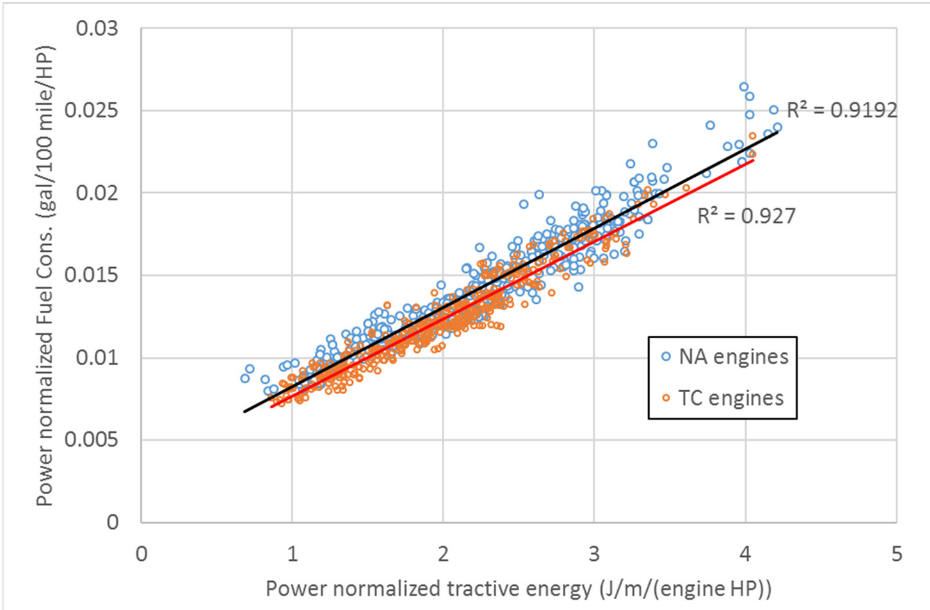
However, the effect of using engine displacement as a normalizing factor in this fleet-wide analysis rather than power does not increase the correlation. Moreover, in EPA's methodology, technology effectiveness adjustments are applied individually to specific technology groups which have constant power density values (hp/L). Thus, although there is a difference between power and displacement normalization when grouping the entire fleet together, in EPA's methodology, there is a perfect correlation between the displacement specific and power specific models, as shown in Figure 14.

Key takeaway: *The use of displacement as a normalization metric has no particular advantage over the use of peak power.*

The effect of technology

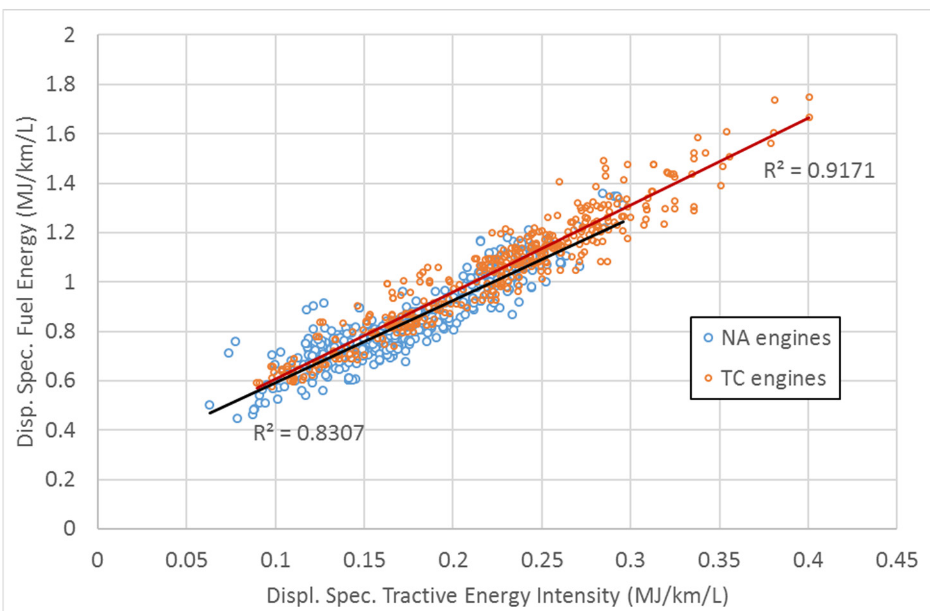
Both power and engine displacement are essentially engine scaling factors that can be used to normalize engine performance. For engines with similar technology, the effect of both is similar; however, differences comes into play when comparing engines with different specific powers – naturally aspirated and turbocharged engines, specifically.

However, in EPA's process, different types of engines (turbocharged, naturally aspirated/GDI, and Atkinson, for example) are treated as different technologies, and are independently assigned power/weight adjustment factors. For example, separating the turbocharged (TC) and naturally aspirated (NA) engines in the power/normalized figure demonstrates two distinct power-normalized lines.



In this case, the turbocharged engines produce a lower normalized fuel consumption that similar-power naturally aspirated engines, indicating a higher efficiency (as expected). The two types of engines fall onto two distinctly different lines, consistent with EPA's process of using different power/weight adjustment factors for each technology.

In a similar way, separating the TC and NA engines in Novation's displacement specific space shows that turbocharged engines tend to be shifted compared to NA engines, into a higher displacement-specific tractive energy, and thus higher efficiency area (again, as expected).



Both normalization methodologies confer the same information when the engine technologies are differentiated. A displacement normalization may be preferable when it is necessary to model the entire fleet with a single correlation. However, EPA has seperated powertrains into distinct categories, depending on the technology package, with each category containing a single engine technology with a single specific power. As shown in Figure 14, the result in this case is a perfect correlation between the two normalization approaches.

Key takeaway: *EPA uses different adjustment factors for different engine technologies, and has no need to represent all technologies in the fleet with a single correlation.*

Appendix A
EPA's Alternate 0-D model of ALPHA results published for the 2016 Proposed Determination

In the September 21st meeting, Novation described an Alternate 0-D Model, which was used to represent EPA's published ALPHA results for the purpose of investigating potential bias in the LPM's representation of ALPHA results. From slide 38 of Novation's presentation, "These re-projected vehicle-level estimates [using an Alternate 0-D Model of EPA's published ALPHA results] can be compared directly to the vehicle-level estimates from the LPM/OMEGA process (MY2025 OMEGA pathway results). The distribution of differences between these two sets of vehicle-level output <u>would indicate the presence and direction of any bias in the ALPHA-to-LPM/OMEGA translation process</u>" (emphasis added.)

EPA does not currently have the 0-D model developed by Novation. In order to further investigate the effectiveness comparison presented above and examine if any bias exists in the ALPHA-to-LPM/OMEGA translation process, EPA generated an Alternate 0-D model. This Alternate 0-D model was created using the published ALPHA results from the Proposed Determination using the following steps which we believe is consistent with the overall approach described by Novation in their September 21st presentation. As defined on slide 34 of the Novation presentation, EPA utilized the same model form shown in Equation 2, with the EPA-developed model coefficients shown in Table 7.

Equation 2 $$\mathbf{DSFEI = \beta_0+\beta_1 * DSTEI}$$

Where DSFEI = displacement specific fuel energy intensity [MJ/km/L]
DSTEI = displacement specific tractive energy intensity [MJ/km/L]
β_0, β_1 = model coefficients determined by linear regression (see Table 7)

An example of the EPA's determination of Alternate 0-D model coefficients is shown in Figure 18 for 24 bar turbocharged engines with TRX22 transmissions. The ALPHA results are provided for each of the six exemplar vehicles, which can be generally distinguished by road load levels, with three low road load ALPHA classes[8] (LPW_LRL, MPW_LRL, HPW), and three high road load ALPHA classes (LPW_HRL, MPW_HRL, Truck.) Figure 18 indicates that Displacement Specific Fuel Energy Intensity (DSFEI) estimates produced by the 0-D model are sensitive to how the ALPHA results are grouped for the linear regression. The low road load exemplar vehicles tend to have higher DSFEI values for a given Displacement Specific Tractive Energy Intensity (DSTEI) values than the high road load exemplar vehicles. Rather than group all six exemplar vehicles together, EPA's assessment retains the resolution of the original ALPHA results for the Alternate 0-D model by fitting separate coefficients to the high road load (HRL) and low road load (LRL) exemplar groups.

Another example of EPA's determination of Alternate 0-D model coefficients (Figure 19) shows ALPHA results for packages containing GDI engines and various transmissions in the LRL exemplar group. As with the road load groups above, delineating between transmission technologies for a given engine is required in order to properly characterize the original ALPHA results. An aggregation of transmission technologies would result in an overestimation of CO_2 emissions (and underestimation of

[8] LPW, MPW, and HPW: Low Power to Weight ratio, Medium Power to Weight ratio, and High Power to Weight ratio respectively.
LRL and HRL: Low Road Load and High Road Load respectively.
For more information on these definitions refer to the Technical Support Document for the 2016 Proposed Determination.

powertrain efficiencies) for more advanced technology packages such as those with TRX22 transmissions.

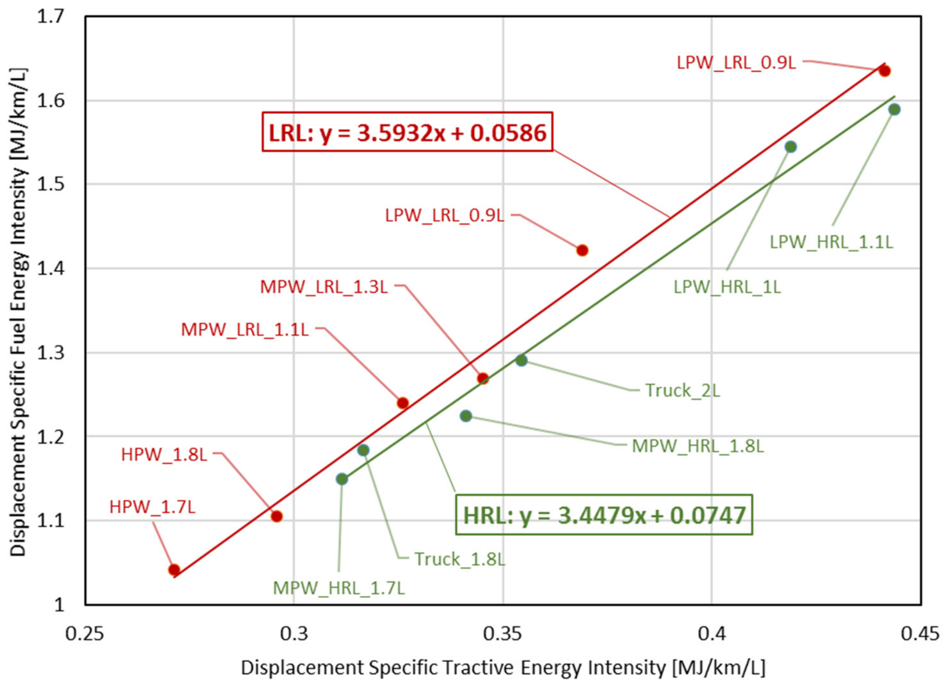


Figure 18 Example of EPA Alternate 0-D Model Coefficient Determination: 24 bar turbocharged engines with TRX22 transmissions, showing two road load groups

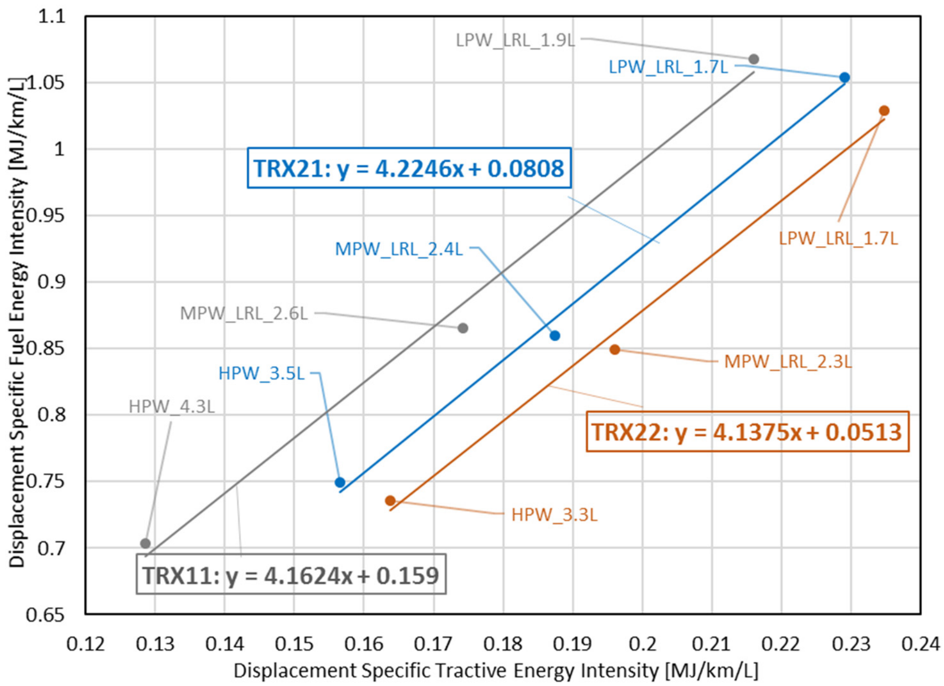


Figure 19 Example of EPA Alternate 0-D Model Coefficient Determination: GDI (SI, NA), Low Road Load (LRL) group, showing three different transmissions

As shown in Table 7, EPA's Alternate 0-D model avoids aggregation of transmission technologies or road load groups. The maximum resolution of the published ALPHA results is thus retained, with separate model coefficients assigned to each combination of engine and transmission, and distinguishing between low and high road load groups.

Table 7 EPA Alternate 0-D model of published ALPHA runs

Engine, in ALPHA runs	Trans, in ALPHA runs	Road Load Group	β1	β0	R2
SI,24bar TC, cooled EGR	TRX21	LRL	3.6713	0.0922	0.9995
		HRL	3.5487	0.0982	0.9983
	TRX22	LRL	3.5932	0.0586	0.9885
		HRL	3.4479	0.0747	0.9891
SI,NA	TRX11	LRL	4.1624	0.159	0.992
		HRL	3.8498	0.1816	0.9994
	TRX21	LRL	4.2246	0.0808	0.9949
		HRL	3.8743	0.1113	0.9994
	TRX22	LRL	4.1375	0.0513	0.9939
		HRL	3.8188	0.0804	0.9999
SI,NA,Atkinson	TRX11	LRL	3.7581	0.2022	0.9922
		HRL	3.5364	0.2104	0.9991
	TRX21	LRL	3.8128	0.1243	0.9945
		HRL	3.4584	0.163	1.0000
	TRX22	LRL	3.7844	0.0833	0.9931
		HRL	3.4375	0.1226	0.9998
SI,NA,Atkinson cooled EGR	TRX21	LRL	3.4007	0.1282	0.9935
		HRL	3.1175	0.1653	0.9971
	TRX22	LRL	3.3445	0.0894	0.9916
		HRL	3.057	0.1288	0.9958

SI,NA,Atkinson cooled EGR, cyl deac	TRX21	LRL	3.4671	0.0941	0.9943
		HRL	3.1859	0.1309	0.9967
	TRX22	LRL	3.3918	0.0694	0.9852
		HRL	3.079	0.1126	0.991

Applying EPA's Alterative 0-D model to the OMEGA-generated technology pathways first requires estimating an engine displacement for the particular vehicle in the OMEGA analysis. This involves estimating the required power of the new technology package to maintain vehicle performance neutrality. To achieve this, the Power-to-Weight relationships among the various technology packages in the ALPHA exemplar runs were used to generate Power-to-Weight multipliers as shown in Equation 3. Once the appropriate multiplier was determined for a particular baseline vehicle's original and future technology packages, it was then applied to the baseline vehicle's power-to-weight ratio to produce an estimate of the power of the future vehicle as shown in Equation 4.

Equation 3 $$\text{PtoW Multiplier}_{TP00toTPnew} = 1 + (\text{WtoP}_{TPnew} - \text{WtoP}_{TP00}) / \text{WtoP}_{TP00}$$

where:
WtoP_{TP00} = Exemplar Weight to Power ratio of original baseline technology package, TP00 [100lbETW/hp]
WtoP_{TPnew} = Exemplar Weight to Power ratio of future technology package, TPnew [100lbETW/hp]

Equation 4 $$\text{Power}_{future\ vehicle} = \text{PtoW Multiplier}_{TP00toTPnew} * (\text{Power}_{baseline\ vehicle}/\text{Weight}_{baseline\ vehicle}) * \text{Weight}_{futureveh}$$

Within each of the five engine technologies in the published ALPHA results, power densities are highly consistent across the six ALPHA classes and transmission types. Using the approach described by Novation, engine displacements of OMEGA's future vehicles are estimated using Equation 5 based on the power density values shown in Table 8 and the power estimates from Equation 4.

Equation 5 $$\text{Engine Displacement}_{future\ vehicle} = \text{Power}_{future\ vehicle} / \text{Power Density}_{TPnew}$$

Table 8 Representative Power Densities Engine Technologies in Published ALPHA Results

Engine Description	Power Density [kW/L]
SI,NA	55.1
SI, Atkinson 2	57.8
SI, Atkinson 2, cooled EGR, cyl deac	57.8
SI, 24bar BMEPTC	97.8

Table 9 shows example results from the above process of estimating engine displacements for future OMEGA packages with a 24bar turbocharged engine and without start-stop.

Table 9 MY2025 OMEGA Vehicles with TSD24 Technology Package and without Start-Stop

OMEGA Index	Carline Name	Baseline Technology Package (TP00)				Alternate 0-D Model of Future Technology Package (TP10)		
		Technology Package Contents	Power [hp]	ETW [lbs]	Weight/ Power [lb ETW/hp]	WtoP Multiplier	Power [hp]	Displacement [L]
473	200 AWD	|LUB|EFR1|V6|VVT|TRX21|EPS|LRRT1|SAX-NA|WRtech- 2|WRpen- 0|WRnet- 2|	295	4000	13.56	1.066	180.97	1.9
474	200 AWD	|LUB|EFR1|V6|VVT|TRX21|EPS|LRRT1|SAX-NA|WRtech- 2|WRpen- 0|WRnet- 2|	295	4000	13.56	1.066	180.97	1.9
475	300	|LUB|EFR1|V6|VVT|TRX21|EPS|LRRT1|SAX-NA|WRtech- 0|WRpen- 0|WRnet- 0|	292	4250	14.55	1.066	175.72	1.8

476	300	|LUB|EFR1|V6|VVT|TRX21|EPS|LRRT1|SAX-NA|WRtech- 0|WRpen- 0|WRnet- 0|	292	4250	14.55	1.066	175.72	1.8
478	300 AWD	|LUB|EFR1|V6|VVT|TRX21|EPS|SAX-NA|WRtech- 0|WRpen- 0|WRnet- 0|	292	4500	15.41	1.066	175.60	1.8
479	300 AWD	|LUB|EFR1|V6|VVT|TRX21|EPS|SAX-NA|WRtech- 0|WRpen- 0|WRnet- 0|	292	4500	15.41	1.066	175.60	1.8
481	Challenger	|LUB|EFR1|V6|VVT|TRX21|EPS|LRRT1|SAX-NA|WRtech- 2.5|WRpen- 0|WRnet- 2.5|	305	4250	13.93	1.066	187.86	1.9
482	Challenger	|LUB|EFR1|V6|VVT|TRX21|EPS|LRRT1|SAX-NA|WRtech- 2.5|WRpen- 0|WRnet- 2.5|	305	4250	13.93	1.066	187.86	1.9
499	Charger	|LUB|EFR1|V6|VVT|TRX21|EPS|LRRT1|SAX-NA|WRtech- 0|WRpen- 0|WRnet- 0|	292	4250	14.55	1.066	175.72	1.8
500	Charger	|LUB|EFR1|V6|VVT|TRX21|EPS|LRRT1|SAX-NA|WRtech- 0|WRpen- 0|WRnet- 0|	292	4250	14.55	1.066	175.72	1.8
502	Charger AWD	|LUB|EFR1|V6|VVT|TRX21|EPS|SAX-NA|WRtech- 0|WRpen- 0|WRnet- 0|	292	4500	15.41	1.066	175.60	1.8
503	Charger AWD	|LUB|EFR1|V6|VVT|TRX21|EPS|SAX-NA|WRtech- 0|WRpen- 0|WRnet- 0|	292	4500	15.41	1.066	175.60	1.8
2089	QX70 AWD	|LUB|EFR1|V6|VVT|VVLTD-OHC-V6|TRX21|EPS|SAX-NA|WRtech-0|WRpen- 0|WRnet- 0|	325	4750	14.62	1.066	195.32	2.0

Note: After LDB removal, TP10 contains = |EFR2| I4| VVT| VVLTD-OHC-I4| EGR| DI| TURB24| OC1| TRX22| IACC2| EPS| Aero2| LRRT2~~| LDB~~| SAX-NA| WRtech- 15| WRpen- 0| WRnet- 15|

EPA's Alternate 0-D model was developed for this memo for the purpose of estimating CO_2 emissions for individual vehicles and OMEGA-applied technology packages based only on the published ALPHA results, without requiring additional custom ALPHA runs.

Appendix B
EPA's power specific 0-D model of ALPHA results published for the 2016 Proposed Determination

Equation 6

$$PSFEI = \beta_0+\beta_1*PSTEI$$

Where PSFEI = power specific fuel energy intensity [MJ/km/hp]
PSTEI = power specific tractive energy intensity [MJ/km/hp]
β_0, β_1 = model coefficients determined by linear regression (see Table 10)

Table 10 EPA power specific 0-D model of published ALPHA runs

Engine, in ALPHA runs		Trans, in ALPHA runs	Road Load Group	β1	β0	R2
SI,24bar TC, cooled EGR		TRX21	LRL	3.6730	0.6989	0.9995
			HRL	3.5495	0.7463	0.9983
		TRX22	LRL	3.5949	0.4426	0.9885
			HRL	3.4493	0.5659	0.9892
SI,NA		TRX11	LRL	4.1662	2.1414	0.9920
			HRL	3.8510	2.4526	0.9994
		TRX21	LRL	4.2282	1.0844	0.9949
			HRL	3.8745	1.5047	0.9994
		TRX22	LRL	4.1387	0.6915	0.9939
			HRL	3.8192	1.0868	0.9999
SI,NA,Atkinson		TRX11	LRL	3.7622	2.5978	0.9922
			HRL	3.5379	2.7076	0.9991
		TRX21	LRL	3.8149	1.5982	0.9945
			HRL	3.4586	2.1014	1.0000
		TRX22	LRL	3.7875	1.0675	0.9932

			HRL	3.4392	1.5760	0.9998
SI,NA,Atkinson cooled EGR		TRX21	LRL	3.4028	1.6490	0.9935
			HRL	3.1174	2.1313	0.9972
		TRX22	LRL	3.3476	1.1456	0.9916
			HRL	3.0586	1.6563	0.9958
SI,NA,Atkinson cooled EGR, cyl deac		TRX21	LRL	3.4688	1.2101	0.9944
			HRL	3.1857	1.6885	0.9967
		TRX22	LRL	3.3947	0.8889	0.9853
			HRL	3.0801	1.4487	0.9910