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Impacts of crediting zero-emission vehicles in the upcoming federal regulation for criteria pollutants from heavy-duty engines and vehicles

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In August 2021, President Biden issued an executive order instructing the Environmental Protection Agency (EPA) to update emission standards for nitrogen oxides (NO_x) for heavy-duty engines and vehicles beginning in model year 2027. The administration also ordered the consideration of zero-emission vehicles (ZEVs) in these updates (Exec. Order No. 14037, 2021). Consequently, the EPA announced that new standards for criteria pollutant emissions from heavy-duty vehicles will be finalized by December 2022 and take effect in model year 2027 (EPA, 2021).

The EPA is not the first agency to consider incorporating ZEVs into NO_x regulations. On December 22,2021, the California Air Resources Board (CARB) finalized new criteria pollutant standards starting in model year 2024 (Kelly and Sharpe, 2022). Along with these new standards, CARB will update their averaging banking and trading (ABT) program to allow manufacturers to generate NO_x credits from sales of ZEV power trains. This ABT program, which will terminate after model year 2026, is designed to incentivize ZEV sales beyond the state-wide requirements mandated in the Advanced Clean Trucks (ACT) regulation (Buysse, 2020).

Starting in model year 2027, the EPA could exclude ZEVs from NO_x ABT, which would align with CARB's regulatory framework, or could instead elect to credit ZEVs through several different mechanisms. Allowing manufacturers to generate NO_x credits through ZEV power trains could incentivize production of ZEVs but runs the risk of disincentivizing improvements in internal combustion engines (ICEs) technology because of the ability to average out high-emitting ICEs with ZEV credits. In this paper, we briefly overview the EPA's current ABT program for criteria pollutants and how CARB will incorporate ZEVs into its ABT program for NO_x. We then assess the impact that different crediting schemes could have on the required improvements for ICE NO_x emissions by considering a fictional manufacturer producing both ZEV power trains

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THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION and ICE engines. Finally, we provide recommendations for the EPA to consider as it develops its rulemaking to reduce criteria pollutant emissions from heavy-duty engines and vehicles.

Summary of current EPA ABT program

The EPA has emissions limits in place on heavy-duty engines for a variety of criteria pollutants including NO_x, particulate matter (PM), and non-methane hydrocarbons (NMHC). To allow for flexibility in achieving emission standards, EPA has an averaging, banking, and trading (ABT) program through which manufacturers can earn credits for producing engine families with family emission limits (FELs) below emission standards. Manufacturers can then use these credits to offset emissions from other engine families that do not meet the standard. These credits can also be traded to other manufacturers or banked for future years.

For heavy-duty diesel engines (HDD), EPA allows ABT for NO_x and PM emissions. There are 3 averaging sets for each pollutant, determined by weight class of the vehicle. For PM, a 4th averaging set exists for all HDDs used in urban buses, regardless of GVWR. For heavy-duty Otto cycle engines (HDO), averaging is allowed for NO_x and NMHC. To restrict manufacturers from producing engines with excessively high emissions, each pollutant also has an FEL cap, the maximum FEL at which an engine can be certified. Table 1 lists information about averaging sets for each engine classification.

Table 1. Weight classification, useful life, and averaging sets available for each heavy-duty vehicle classification. Checkmarks indicate availability of the averaging set for a given engine class and pollutant.

Engine family		GVWR (lbs)	Useful life (miles)		NO_x	PM	NMHC
Diesel	HHDD	> 33,000	435,000	Averaging Set?	✓	✓*	✗
	MHDD	19,501 - 33,000	185,000		✓	✓*	✗
	LHDD	14,001-19,500	110,000		✓	✓*	✗
HDO		> 10,000	110,000		✓	✗	✓
			Emissions Limit (g/bhp-hr)		0.2	0.01	0.14
			FEL Cap (g/bhp-hr)		0.5	0.02	0.3

*Heavy-duty diesel engines used in urban buses are subject to a separate PM averaging set regardless of weight classification.

Credits and deficits for each averaging set are measured in megagrams and are calculated using equation 1.

$$Credits = (Std - FEL) \times CF \times UL \times Prod \times 10^{-6} \quad (1)$$

Std = Emission standard for given pollutant (g/bhp-hr)

FEL = Family Emission Limit – Certified emissions level for given engine family (g/bhp-hr)

CF = Transient Cycle Conversion Factor – total integrated FTP cycle work divided by equivalent mileage (6.3 miles for Otto or 6.5 miles for diesel) – (bhp-hr/mile)

UL = Useful life for given engine family (miles)

Prod = Number of engines produced in given engine family for a single model year

10^{-6} = Conversion from grams to megagrams

Credits are generated when an engine family is certified below the emission standard and can be used to average out emissions from engine families above the emission limit. In the current system, neither heavy-duty hybrid power trains nor heavy-duty ZEVs can generate credits toward any of the criteria pollutant ABT averaging sets. With the upcoming federal regulation expected to take effect in model year 2027, the EPA may consider integrating ZEVs into the ABT program as an incentive to manufacturers to transition to ZEV production.

Incorporation of ZEVs in the CA-ABT program

The Clean Air Act gives California unique authority to set more stringent emission standards than the federal regulations (Clean Air Act, 1963). Despite this authority, California has aligned with the EPA's heavy-duty emission standards and ABT provisions since 2004. As of model year 2022, California Air Resources Board (CARB) is using a new, separate ABT crediting program (CA-ABT) to accompany the updated emission standards and useful lifetimes in the state. Importantly, CA-ABT allows manufacturers to generate NO_x credits through sales of ZEVs.

ZEV credits for CA-ABT will be calculated using equation 2. Equation 2 resembles equation 1 closely, with the assumption that for all ZEVs, the FEL will be zero. Additionally, CF in equation 1 is replaced by ECF in equation 2. Although ZEV credits can be used in any averaging set at the manufacturer's discretion, the NO_x standard and useful life used to calculate them correspond to diesel vehicles in the same weight class.

$$Credits = Std \times ECF \times UL \times Sales \times 10^{-6} \qquad (2)$$

Std = Emission standard for given pollutant for diesel weight class corresponding to ZEV family

ECF = Transient Cycle Conversion Factor – total integrated cycle bhp-hr for the ZEV family during FTP cycle divided by equivalent mileage divided by 6.8 miles for diesel

UL = Useful life for diesel weight class corresponding to ZEV family

Sales = CA sales volume for ZEV family

10^{-6} = Conversion from grams to megagrams

This crediting program was specifically implemented to incentivize a transition to ZEVs (Kelly and Sharpe, 2022). It complements the ACT regulation, which starting in model year 2024 will require a minimum percentage of ZEVs within the heavy-duty fleet. CARB has included ZEVs in its NO_x ABT to incentivize their production beyond the levels required in the early years of ACT (California Air Resources Board, 2020), and will terminate the ZEV crediting program after model year 2026 so as not to dilute the impact of the strict NO_x standards for ICEs beginning in model year 2027.

ZEV crediting options for EPA

The EPA is still developing its regulatory proposal for criteria pollutant emissions, and it is unclear what the agency will propose in terms of NO_x emission limits, useful life provisions, test procedures, and other elements for the regulation. In our analysis, we assume that the EPA aligns its regulation with CARB on all of these key regulatory design parameters. The primary objective is to explore scenarios for how the EPA might credit ZEVs in its upcoming regulation. We outline some of the most viable crediting schemes and discuss the implications for emission reduction requirements for ICEs under each option. To do so, we consider a fictional manufacturer producing an increasing number of ZEV power trains and illustrate to what degree credits generated under each policy option can offset the need for NO_x emission reductions from diesel engines.

We consider a manufacturer producing 1,000 Class 8 engines/vehicles per model year. We assume this manufacturer precisely follows California's ACT regulation for Class 8 trucks, meaning it will increase from 5% ZEV sales in 2024 to 30% in 2030. The remainder of sales are diesel engines. A breakdown of diesel and ZEV sales in the years of interest (model years 2027 and 2030) is shown in Table 2.

Table 2. Sales of zero-emission power trains and diesel engines for an example manufacturer in 3 model years, as well as the CA NO_x standard and useful life in each of those years.

Year	NO_x standard (g/bhp-hr)	Useful life (miles)	ZEV power train sales	Diesel sales
2027	0.035	600,000	150	850
2030	0.035	600,000	300	700

Equation 2 is used to calculate credits generated by ZEV power train sales. The ECF is set to 4 bhp-hr/mile for all ZEVs, estimated from the UDDS total work calculated for a Class 8 drayage ZEV by UC Riverside (Kent Johnson, 2015). Generating emission credits will allow the example manufacturer to certify diesel engines at a higher average FEL than the set standard, which will be calculated by rearranging equation 1:

$$FEL = Std + \frac{Credits}{CF \times UL \times Prod \times 10^{-6}}$$

The CF term is estimated as 5 bhp-hr/mile based on FTP work calculations for Class 8 diesel vehicles (Arvind Thiruvengadam, 2014). In many crediting schemes, including the CARB scheme, the manufacturer may use ZEV credits to offset ICE emissions from any weight class, but we assume the manufacturer is using all credits to offset emissions from Class 8 diesel engines. Further, while the manufacturer could bank ZEV credits for future years or trade them to another manufacturer, we assume all credits go toward averaging emissions from their own sales. Example calculations for generated ZEV credits and allowable average diesel FEL are shown in the Appendix.

Option 1: Status quo: no credits for ZEV sales

EPA could elect to continue excluding ZEVs from ABT schemes even after aligning its emissions limits with CARB. This option has the benefit of requiring manufacturers to improve the NO_x emissions of their entire ICE fleet but would include no incentive for manufacturers to sell ZEVs. In this scenario, ZEVs would generate no credits, and the average allowable FEL for the fictional manufacturer would equal 0.035 g/bhp-hr, the NO_x standard for diesel vehicles in both 2027 and 2030. This scenario would lead to the most stringent ICE NO_x emissions limit.

Because CARB's NO_x crediting scheme terminates after model year 2026, this option has the benefit of allowing EPA to completely harmonize the federal ABT program with the CA-ABT, eliminating the need for separate averaging sets for California and the rest of the U.S.

Option 2: Credit ZEVs like diesel engines with zero NO_x emissions

EPA could adopt the ZEV crediting scheme that CARB will use for model years 2022 through 2026. In this scheme, ZEV sales would be credited as diesel engines with an FEL value of 0. These credits would then be available for use in any of the NO_x averaging sets, regardless of weight class or engine type. Table 3 shows how the example manufacturer could use credits generated by ZEVs in this crediting scheme to offset emissions from its diesel fleet. Here, as the percentage of ZEVs in the manufacturer's fleet increases from 2027 to 2030, so do the credits generated by ZEV sales, leading to an increase in the average allowable FEL from the diesel fleet. By model year 2030, the allowable FEL of the manufacturer's diesel sales is over 30% higher than the standard.

Table 3. Credits generated by Zero-emission power train sales and allowable Family Emission Limit for diesel engines for example manufacturer under California crediting scheme

Year	Credits generated by ZEVs	Allowable average FEL for diesels	Percentage increase in allowable average FEL for diesels
2027	12.60	0.040	14.1%
2030	25.20	0.047	34.3%

While this option is similar to the CARB crediting scheme, it is important to note that CARB's scheme terminates after model year 2026, and EPA's scheme will not start until model year 2027. Therefore, this option does not harmonize the EPA and CARB standards and would necessitate the continuation of separate federal and CA-ABT programs.

Option 3: Super credits for ZEVs

To further incentivize ZEVs, EPA could introduce super credits for NO_x emissions for ZEV power trains. Super credits are generated by multiplying the credits generated by ZEVs by a set number. In Table 4, the effect of this system on the allowable average FEL for diesel vehicles produced by the example manufacturer are shown for multipliers of 1.5, 2, and 2.5. The average FEL allowed for the diesel fleet increases as this multiplier gets higher.

Table 4. Credits generated and allowable average FEL for diesel engines for example manufacturer with super credit scheme with various values for credit multiplier

Year	Multiplier	Credits generated by ZEVs	Allowable average FEL for diesels	Percentage increase in allowable average FEL for diesels
2027	1.5	18.90	0.042	21.2%
	2	25.20	0.045	28.2%
	2.5	31.50	0.047	35.3%
2030	1.5	37.80	0.053	51.4%
	2	50.40	0.059	68.6%
	2.5	63.00	0.065	85.7%

The purpose of super credits is to further incentivize ZEV production, but this incentive comes at a cost of reduced stringency on ICE vehicles. For the 2.5 multiplier scenario, this option results in allowable diesel emission certification values that are nearly double the case of Option 1, where ZEVs cannot generate NO_x credits.

Option 4: Early credits for ZEVs

While the EPA regulation is not expected to take effect until model year 2027, EPA may incentivize ZEVs through NO_x credits starting in earlier years. To do so, EPA could award credits for ZEVs sold before model year 2027 for use in complying with the NO_x standard for model year 2027 and beyond. These credits could be banked for use once the new standards take place. In this scheme, the fictional manufacturer would generate about 18.5 NO_x credits between model years 2024 and 2026, as shown in detail in Table 5.

Table 5. Early credits generated by example manufacturer from model years 2024 through 2026.

Year	ZEV power train sales	Credits generated
2024	50	4.20
2025	70	5.88
2026	100	8.40
Sum		**18.48**

Theoretically, these credits could be used to offset the stringency of ICE NO_x emissions in any year between 2027 and 2030. Table 6 illustrates how adding early credits to the ZEV credits generated in Option 2 would affect the allowable average FEL for a manufacturer's diesel fleet. While the manufacturer could allocate these credits in any manner it sees fit, we've included scenarios where the manufacturer uses all 18.5 credits in one model year and where the manufacturer splits the credits evenly among all 4 model years. Example calculations for early credits are shown in the Appendix.

Table 6. Effect of early credits generated on allowable average Family Emission Limit for diesel fleet when used in one fiscal year or split evenly between every year

Credits usage	Year	ZEV power train sales	ZEV credits	Early credits	Total credits	Allowable average FEL for diesels	Percentage increase in allowable average FEL for diesels
All in one year	2027	150	12.60	18.48	31.08	0.047	34.8%
	2030	300	25.20	18.48	43.68	0.056	59.4%
Split evenly 2027-2030	2027	150	12.60	4.62	17.22	0.042	19.3%
	2030	300	25.20	4.62	29.82	0.049	40.6%

The effect of this scheme depends on how a manufacturer chooses to divide these early credits. However, because the additional credits are gained in early years, when ZEVs will only make up a small portion of the manufacturer's fleet, they only greatly increase the average emissions limits of the ICE fleet if they are bundled into a single year.

Option 5: Early and super credits for ZEVs

EPA could elect to combine early and super credit programs to further incentivize ZEV production both before and after model year 2027. We consider a scenario where the manufacturer generates double credits (multiplier = 2.0) for ZEVs produced both before and after model year 2027, but EPA could choose any multiplier to reach the desired incentive level. Example calculations for early and super credits are shown in the Appendix.

Table 7. Effect of early and super credit scheme on average diesel emissions for example manufacturer

Credits usage	Year	ZEV power train sales	ZEV credits	Early credits	Total credits	Allowable average FEL for diesels	Percentage increase in allowable average FEL for diesels
All in one year	2027	150	25.20	36.96	62.16	0.059	69.6%
	2030	300	50.40	36.96	87.36	0.077	118.9%
Split evenly 2027-2030	2027	150	25.20	9.24	34.44	0.049	38.6%
	2030	300	50.40	9.24	59.64	0.063	81.1%

The effect of this scheme would depend significantly on the multiplier chosen by the EPA, but Table 7 illustrates the general trend of greatly increased ICE emission limits through this program. In this scheme, the standards on ICE vehicles would be dramatically relaxed relative to the stated emission limits.

Summary

Figure 1 illustrates how our example NO_x crediting schemes for ZEVs in EPA's upcoming regulation lead to relaxed standards for the diesel fleet. Any system that allows ZEVs to generate credits toward NO_x ABT will lead to less stringent NO_x limits for ICE vehicles. In Option 5 (both super and early credits), the allowable average FEL for ICEs could nearly double by 2030. It will be important for the EPA to consider these potential impacts when developing new criteria pollutant standards and compliance flexibility mechanisms.

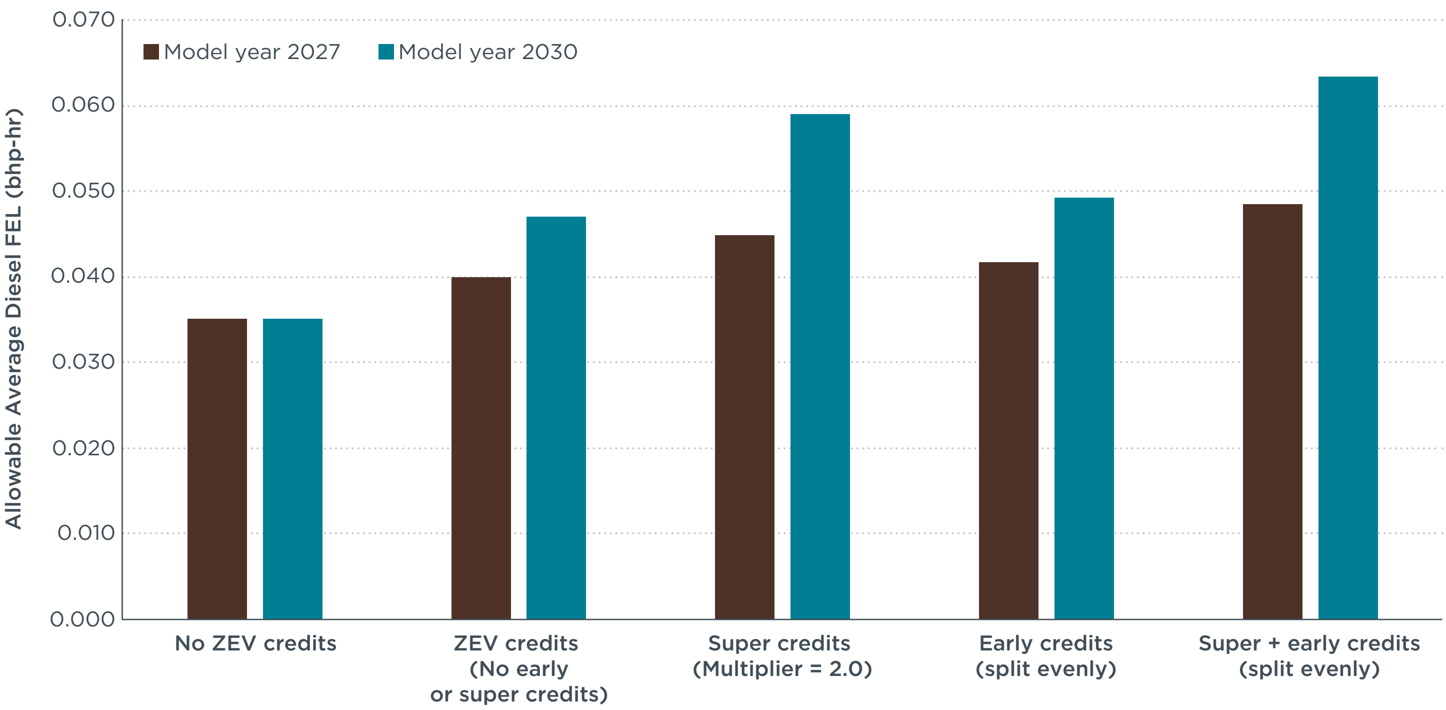

Figure 1. Average allowable Family Emission Limit for diesel fleet for example manufacturer using each crediting scheme

While we have chosen a simple scenario of one manufacturer averaging out Class 8 ZEV sales with Class 8 diesel engines, ICE emission levels would also depend greatly on how the manufacturer elects to use its generated credits. In the CARB scheme, manufacturers are allowed to use ZEV credits in any averaging set, regardless of weight class or engine type; the allowable emissions for a manufacturer will naturally depend on where they choose to use these credits. Further, manufacturers could bank ZEV credits for future years, leading to more uncertainty in average emissions in any given year. In general, crediting schemes that lead to a higher value of NO_x credits generated by ZEVs will also lead to higher uncertainty in how they will be used.

Finally, this list of options for crediting is not exhaustive but meant to illustrate that, in the case of NO_x crediting, more generous ZEV crediting programs can quickly reduce requirements for ICE emissions. The exact extent of this decreased stringency depends on how the credits are generated and used.

Policy Recommendation

Incentivizing heavy-duty ZEVs is a priority for the EPA, but it is worth considering whether NO_x crediting is the best avenue for doing so. Overly generous crediting schemes may act less to incentivize a transition to ZEVs and more to undermine requirements for conventional vehicles by allowing manufacturers to produce ICEs with higher NO_x emissions.

A more predictable and stringent policy for ensuring a transition to ZEVs would likely be to regulate a percentage of sales that come from heavy-duty ZEVs, similar to what has been enacted in California through the ACT. Absent a ZEV-specific regulation, it may be more beneficial to incentivize ZEVs via the ABT program in the next phase of regulation (i.e., Phase 3) for greenhouse gases and fuel efficiency for heavy-duty vehicles.

There are also benefits to be gained from aligning with the California ABT system. Starting in 2022, manufacturers will offer CA-only products to comply with their more stringent NO_x standards. If the federal government adopts the same standards and crediting system, manufacturers can return to a single set of products once again in 2027.

For these reasons, we recommend that EPA not include ZEVs in NO_x crediting schemes and instead find other avenues to incentivize their production. Including ZEVs in NO_x crediting may incentivize transitions to ZEVS, but will most likely increase ICE NO_x emissions in the process. We recommend that the EPA find other methods to catalyze ZEV production, preferably through direct regulation or as part of the Phase 3 greenhouse gas and fuel efficiency rulemaking.

Appendix

Credits example calculation (Model year 2027)

To calculate credits generated:

$$Credits = Std \times ECF \times UL \times Sales \times 10^{-6}$$

For model year 2027,

$$Credits = 0.035\ \frac{g}{bhp\text{-}hr} \times 4\ \frac{bhp\text{-}hr}{mile} \times 600{,}000\ miles \times 150 \times 10^{-6}$$
$$= 12.60\ Mg$$

To calculate allowable average FEL for diesels:

$$FEL = Std + \frac{Credits}{CF \times UL \times Prod \times 10^{-6}}$$

$$FEL = 0.035\ \frac{g}{bhp\text{-}hr} + \frac{12.60\ Mg}{5\ \frac{bhp\text{-}hr}{mile} \times 600{,}000\ miles \times 850 \times 10^{-6}}$$
$$FEL = 0.040\ \frac{g}{bhp\text{-}hr}$$

Early credits example calculation

$$Credits_{2024} = 0.035\ \frac{g}{bhp\text{-}hr} \times 4\ \frac{bhp\text{-}hr}{mile} \times 600{,}000\ miles \times 50 \times 10^{-6}$$
$$= 4.20\ Mg$$

$$Credits_{2025} = 0.035\ \frac{g}{bhp\text{-}hr} \times 4\ \frac{bhp\text{-}hr}{mile} \times 600{,}000\ miles \times 70 \times 10^{-6}$$
$$= 5.88\ Mg$$

$$Credits_{2026} = 0.035\ \frac{g}{bhp\text{-}hr} \times 4\ \frac{bhp\text{-}hr}{mile} \times 600{,}000\ \text{miles} \times 100 \times 10^{-6}$$
$$= 8.48\ Mg$$

$$Total\ Early\ credits = Credits_{2024} + Credits_{2025} + Credit_{2026}$$
$$= 4.20\ Mg + 5.88\ Mg + 8.48\ Mg = 18.48\ Mg$$

Use all early credits in model year 2027:

$$Total\ Early\ credits = Credits_{2027} + Early\ credits$$

$$= 12.60\ Mg + 18.48\ Mg = 31.08\ Mg$$

$$FEL_{diesel} = 0.035\ \frac{g}{bhp\text{-}hr} + \frac{31.08\ Mg}{5\ \frac{bhp\text{-}hr}{mile} \times 600{,}000\ miles \times 850 \times 10^{-6}}$$

$$= 0.047\ \frac{g}{bhp\text{-}hr}$$

Split credits evenly among model years 2027 through 2030 (i.e., split over 4 model years):

$$Total\ credits = Credits_{2027} + \frac{Early\ credits}{4}$$

$$= 12.60\ Mg + \frac{18.48\ Mg}{4} = 1\ 7.22\ Mg$$

$$\mathrm{FEL}_{diesel} = 0.035\ \frac{g}{bhp\text{-}hr} + \frac{17.22\ Mg}{5\ \frac{bhp\text{-}hr}{mile} \times 600{,}000\ miles \times 850 \times 10^{-6}}$$

$$= 0.042\ \frac{g}{bhp\text{-}hr}$$

Super and early credits (split evenly over 4 years, multiplier = 2.0)

$$Early\ super\ credits = Early\ credits\ (calculated\ above) \times multiplier$$

$$= 18.48\ Mg \times 2.0 = 36.96\ Mg$$

$$Super\ credits_{2027} = credits_{2027} \times multiplier$$

$$12.60\ Mg \times 2.0 = 25.20\ Mg$$

$$Total\ super\ credits = super\ credits_{2027} + \frac{Early\ super\ credits}{4}$$

$$= 25.20\ Mg + \frac{36.96\ Mg}{4} = 34.44\ Mg$$

$$FEL_{diesel} = 0.035\ \frac{g}{bhp\text{-}hr} + \frac{34.44\ Mg}{5\ \frac{bhp\text{-}hr}{mile} \times 600{,}000\ miles \times 850 \times 10^{-6}}$$

$$= 0.49\ \frac{g}{bhp\text{-}hr}$$

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