Updates to ACEEE's Greenercars Rating System for Model Year 2019
American Council for an Energy-Efficient Economy

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This document details our updates for the analysis of model year 2019 cars and light trucks, reflected in the release of ACEEE's Greenercars rankings available at Greenercars.org for model year 2019. Aspects of the methodology not discussed in this memo will remain as described in the report *Rating the Environmental Impacts of Motor Vehicles: ACEEE's Green Book Methodology, 2016 Edition* (Vaidyanathan, Slowik & Junga 2016).

Proposed changes from the model year 2018 methodology are:

- Update the schedule of annual vehicle miles traveled
- Update power sector emission factors based on GREET 1 2018
- Update our analysis of embodied emissions to reflect GREET 2 2018

CHANGES FOR MY2019 GREENERCARS RATINGS

UPDATE TO ANNUAL VEHICLE MILES TRAVELLED SCHEDULE

Greenercars methodology currently utilizes estimates of vehicle miles traveled to calculate emissions related to plug-in vehicle charging across the vehicle's full lifetime. Further, for MY 2019, we propose to begin discounting damage costs associated with in-use criteria emissions as discussed below. Both calculations require a VMT schedule to determine typical vehicle use for each year of its lifetime. To date, in its calculation of plug-in vehicle emissions, ACEEE has used the distribution of lifetime miles highlighted in Table 1 below for both LDVs and LDTs.

Table 1. Vehicle Survival Miles (as a Percentage of Lifetime Travel) Over Assumed 25-Year Lifetime

Age	LDV
0	8.6%
1	8.3%
2	7.9%
3	7.5%
4	7.1%
5	6.8%
6	6.4%
7	5.9%
8	5.4%
9	4.9%
10	4.4%
11	4.0%
12	3.6%
13	3.2%
14	2.8%
15	2.4%
16	2.1%
17	1.8%
18	1.6%
19	1.3%
20	1.1%
21	0.9%
22	0.8%
23	0.6%
24	0.5%

Source: Kliesch 2004

However, these numbers were calculated in 2004 using EPA's MOBILE6 vehicle emissions model vehicle lifetime miles and survival data from the 2002 Transportation Energy Data Book. Since annual VMT and survival rates have changed significantly in the last 14 years, we propose to update the methodology accordingly.

Using annual vehicles miles of travel and survival rates for cars and light trucks from the latest edition of the Transportation Energy Data Book (Davis and Boundy 2018), we calculate updated annual vehicle survival miles as shown in Table 2. Because this vehicle survival schedule includes six additional years over our current source, we propose to extend the VMT survival schedule from 25 years to 30 years. The impact of these changes are discussed at the end of this memo.

Table 2. Annual Vehicle Survival Miles for Cars and Light Trucks by Vehicle Age

Vehicle age (years)	Annual vehicle miles of travel for cars	Survival rate for cars	Vehicle survival miles for cars	Annual vehicle miles of travel for trucks	Survival rate for trucks	Vehicle survival miles for trucks
0	13,843	1.00	7.9%	15,962	1.00	7.8%
1	13,580	1.00	7.7%	15,670	0.99	7.6%
2	13,296	0.99	7.5%	15,320	0.98	7.4%
3	12,992	0.99	7.3%	15,098	0.97	7.2%
4	12,672	0.98	7.1%	14,528	0.96	6.8%
5	12,337	0.97	6.8%	14,081	0.94	6.5%
6	11,989	0.96	6.6%	13,548	0.92	6.1%
7	11,630	0.94	6.2%	13,112	0.89	5.7%
8	11,262	0.92	5.9%	12,544	0.86	5.3%
9	10,887	0.89	5.5%	12,078	0.82	4.9%
10	10,509	0.86	5.2%	11,595	0.78	4.5%
11	10,129	0.83	4.8%	11,131	0.74	4.0%
12	9,748	0.79	4.4%	10,641	0.70	3.6%
13	9,370	0.72	3.8%	10,153	0.65	3.2%
14	8,997	0.61	3.1%	9,691	0.61	2.9%
15	8,629	0.51	2.5%	9,239	0.55	2.5%
16	8,270	0.42	2.0%	8,797	0.50	2.2%
17	7,922	0.33	1.5%	8,383	0.45	1.9%
18	7,586	0.26	1.1%	8,009	0.41	1.6%
19	7,265	0.20	0.8%	7,666	0.36	1.4%
20	6,962	0.16	0.6%	7,358	0.32	1.2%
21	6,679	0.12	0.5%	7,089	0.29	1.0%
22	6,416	0.09	0.3%	6,862	0.26	0.9%
23	6,177	0.07	0.2%	6,684	0.23	0.7%
24	5,963	0.05	0.2%	6,556	0.20	0.6%
25	5,778	0.04	0.1%	6,481	0.17	0.6%
26	5,623	0.03	0.1%	6,466	0.15	0.5%
27	5,499	0.02	0.1%	6,466	0.13	0.4%
28	5,410	0.01	0.0%	6,466	0.12	0.4%
29	5,358	0.01	0.0%	6,466	0.10	0.3%
30	5,358	0.01	0.0%	6,466	0.09	0.3%
Total	278,134		100.0%	310,610		100.0%
Survival-Weighted Lifetime VMT	175,707			203,818		

Source: Transportation Energy Data Book, Edition 36.2

INCORPORATE UPDATES FROM GREET 1 2018 INTO ELECTRICITY EMISSION FACTORS

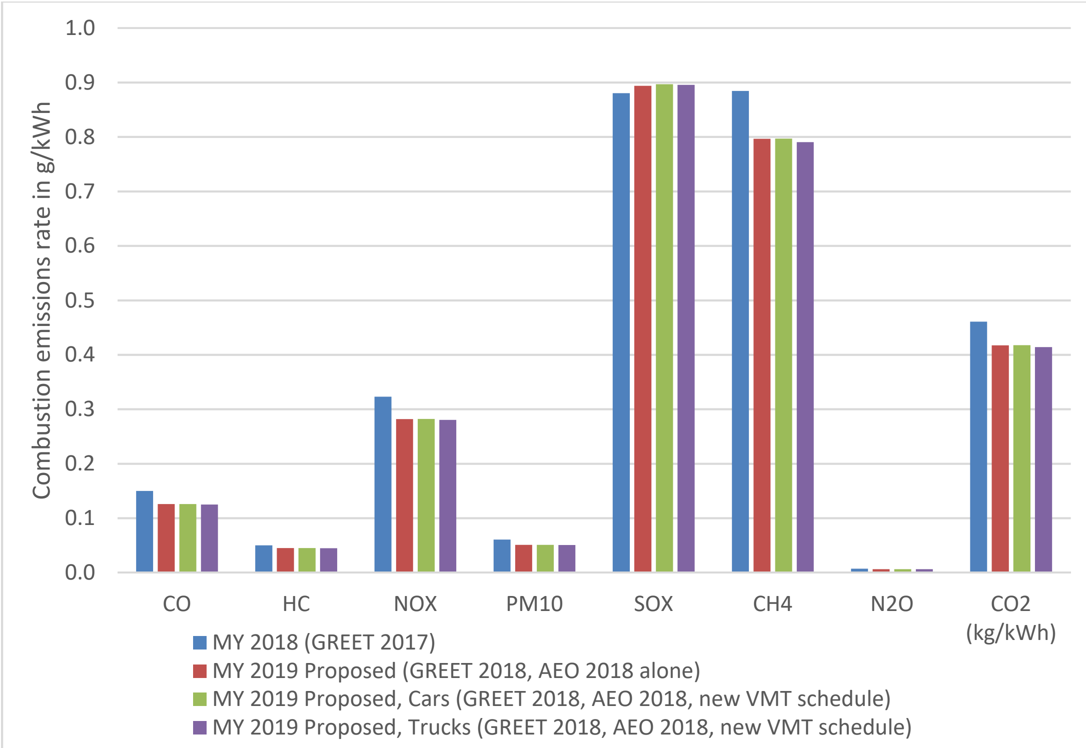
Our methodology for estimating upstream emissions related to electric vehicles is based on Argonne National Lab's GREET emission rates for combustion and feedstock emissions (including T&D losses) for electricity generation based on a current national grid mix and scaled for future years to account for the evolving mix and features of generation sources.

Estimating emissions associated with plug-in vehicle charging requires projections of emissions from electricity generation for future years. We determine a gram-per-mile emission factor for electricity generation using EIA Annual Energy Outlook (AEO) projections which we scale based on expected vehicle miles traveled for each year over its lifetime (Vaidyanathan et al. p.13). We propose to update these emissions factors for Greenercars 2019 by adopting emission factors based on GREET 2018 and AEO 2018.

We first compare the change in emissions rates associated with the update to GREET 2018 and AEO 2018 to our previous emissions rates, but applying the VMT schedule used in prior years. For battery electric vehicles on average, adopting the factors from the updated versions of GREET and AEO results in a 0.8% decrease in the per-mile damage cost (cents/mile) for criteria pollutants, and a 9.4% decrease in per-mile damage cost for greenhouse gasses as compared to the rates used in the MY 2018 ratings.

We then determine the combined impact of the updated emissions rates along with the proposed VMT schedule update, allowing us to determine separate factors for cars and trucks. For plug-in cars, the combined impact results in a 0.6% and 9.4% decrease in criteria and GHG damage costs, respectively. Similarly, for plug-in trucks, damage costs decrease by 0.8% and 10.1%, respectively. Figure 1 compares the emission rates for CO2 and the respective criteria pollutants considered by Greenercars.

Figure 1. Comparison of VMT-adjusted power generation emission factors from GREET 1 2017 and GREET 1 2018, with and without new VMT schedule



The change in lifetime average emissions per kWh for plug-in cars versus plug-in trucks appears to be slightly favorable to trucks. Compared to cars, trucks are expected to drive a greater share of total lifetime miles in the later years of the vehicle's lifetime. Because we scale emission rates using EIA AEO projections to reflect declining generation emissions in future years, plug-in trucks are likely to drive more miles on this projected "cleaner" grid compared to cars.

Incorporate Updates from GREET 2 2018 into Estimate of Embodied Emission Factors

Greenercars ratings use results from ANL's GREET 2 Vehicle-Cycle Model to estimate the emissions impacts of the manufacturing and assembly, disposal, and recycling of a given vehicle. GREET 2 allows us to estimate a vehicle's embodied emissions as a linear function of vehicle weight, battery weight and chemistry, and fuel stack weight depending on the vehicle type and technology being evaluated (Vaidyanathan et al, p.15-17).[1]

Incorporating the GREET 2 2018 update into our calculation of embodied emissions has an insignificant impact for traditional ICE vehicles, but the impact on plug-in vehicles' embodied emissions is large.

GREET 2 2018 Battery Assumptions Update

[1] We calculate a separate linear relationship for each combination of vehicle, powertrain, and fuel types. New combinations of vehicle and powertrain type are appearing on the market, such as mild hybrid pickup trucks. For MY 2019, we added a relationship for hybrid pickup trucks with Li-Ion batteries.

The GREET 2 2018 update incorporates various changes to its lifecycle analysis (LCA) of lithium-ion batteries (LIB) and associated processes (ANL 2018). GREET 2 allows the user to change various characteristics of the vehicle being modeled, including details such a battery chemistry. Most significant for 2018 is the change to the default LIB cathode chemistries and battery designs selected by the model. Adopting the new default cathode chemistry (NMC111) shows a significant increase in lifecycle damage costs for battery manufacturing compared to the chemistry previously selected as default (NMC442) for the GREET 2 model.

The choice of a new default cathode chemistry is meant to better reflect evolving battery designs (Dai et al. 2018). The former default cathode material is not currently used for traction applications, and ANL states that the switch in default cathode chemistry is to reflect the fact that the new default is more common in the market. ANL further describes the basis for these, and other notable changes, in Dai et al. 2018 (p. 6).

To demonstrate the impact of the new cathode material, we provide in table 4 the change in damage costs for two representative vehicles, a BEV SUV (2018 Tesla Model X 75D) and BEV car (2018 Chevrolet Bolt), along with the average change to all vehicles scored. In 2018, the Chevy Bolt had a damage cost of 0.183 cents/mile for embodied criteria emissions. With the GREET 2 2018 updates, the Bolt would see an 83% increase in the embodied emissions component of the EDX, to 0.335 cents/mile. The Tesla Model X sees a similar increase. Plug-in hybrids are also affected by this update, though the impact to EDX is considerably less given the smaller battery size.

Table 4. Effect of GREET 2 2018 update on embodied emissions damage costs (¢/mile) for the average of all vehicles scored, a typical BEV car (2018 Chevy Bolt), and BEV SUV (2018 Tesla Model X 75D)

	Existing Methodology	GREET 2 2018 Update	Difference	% Change
Average Embodied Crit. (¢/mile)	0.134	0.135	0.001	1%
BEV Car Embodied Crit. (¢/mile)	0.183	0.335	0.152	83%
BEV SUV Embodied Crit. (¢/mile)	0.217	0.395	0.178	82%
Average Embodied GHG (¢/mile)	0.100	0.096	-0.003	-3%
BEV Car Embodied GHG (¢/mile)	0.103	0.123	0.020	20%
BEV SUV Embodied GHG (¢/mile)	0.125	0.149	0.024	19%

To understand the cause for the large increases shown in Table 4, we provide the update's effects for each embodied criteria pollutant by evaluating the relevant specifications of the 2018 Chevrolet Bolt.[2] The resulting damage costs for each pollutant[3] is provided in table 5.

Table 5. Comparison of embodied criteria damage costs (¢/mile) for representative BEV (2018 Chevrolet Bolt)

	Existing Methodology	Proposed Update	% Change
NOx (¢/mile)	0.007	0.008	27%
PM10 (¢/mile)	0.021	0.031	44%
SOx (¢/mile)	0.155	0.295	91%
Total	0.183	0.335	83%

With this, we can see that SOx is the most significant driver of the increase in criteria damage cost. As an exercise, we changed the cathode material in the GREET 2 2018 model directly to the former default and found the resulting emissions to be essentially the same as for the MY 2018 release of Greenercars. We, therefore, believe that the resulting increase to embodied criteria damage costs is from the change in cathode material selected by ANL, with seemingly less significant impacts from the other changes described in Dai et al. 2018.

We generally prefer to update the Greenercars methodology to reflect GREET updates so long as the updates are documented. In this instance, we do not fully understand all technical justifications for the changes to the GREET 2 model, nor why criteria emissions are dramatically higher for the NMC111 cathode material. However, reflecting reviewer comments and a subsequent analysis to determine the resulting impact that cathode material choice has on embodied emissions, we adopted GREET's new chosen default cathode material as it more closely represents the emissions impact of manufacturing modern batteries used in today's plug-in vehicles.

IMPACT OF METHODOLOGY CHANGES

To evaluate the impact of the above changes on average EDX and Green Score, we apply them to prior model year data. We compare results from the MY 2018 Greenercars analysis with the changes

[2] 4000 lb. vehicle weight, 944 lb. Li-Ion battery. Specifications obtained from MY 2018 EPA Fuel Economy Guide.
[3] We limit our analysis of embodied emissions to certain criteria pollutants (NOx, PM10, and SOx) and greenhouse gasses (CO2) as per our 2016 methodology report (Vaidyanathan et al. 2016).

that result from each update independently. For MY 2019, we evaluated the effect of adopting GREET 1 and GREET 2 2018 updates, and updating the VMT schedules.

Greenercars converts a vehicle's EDX (in cents per mile) to a Green Score, a value from 0 to 100, using a gamma function (Vaidyanathan et al. 2016). When making changes to our methodology, we determine whether the resulting change in EDX is the result of a real-world change in lifecycle emissions or of a change in methodology. In the case that a change is due purely to methodological changes, we adjust a constant ("C-value") in the gamma function to ensure that Green Scores are comparable across model years and do not fluctuate due to methodological changes. If the proposed methodology update is based on the real world, we do not include it in the calculation of the new C-value.

For the proposed electricity emission factors, we treat the updates as real-world changes, with GREET 1 and AEO largely reflecting an incrementally cleaner power grid today and in the future. GREET 2 impacts in large part reflect the same, except for plug-in vehicles as discussed.[4] We assume the new VMT schedule better reflects modern driving habits and treat this as a real-world update. The update to GREET 1 or GREET 2 had no significant impact on average damage costs across all models.

The overall impact of all changes outlined in this report are highlighted in table 8, reflecting the respective methodology updates. The average Green Score is essentially unchanged since the aforementioned real-world impacts affect only a very small number of vehicles.

Table 8. Overall Impact of Changes on Average EDX (¢/mile)

	All Vehicles	Cars	Light Trucks
MY 2018 Results	1.582	1.48	1.72
Cumulative MY2019 Updates	1.580	1.48	1.71

GREET 2 updates are not significant for traditional vehicles, but the accounting of emissions from battery manufacturing has significantly increased EDX for BEVs, and thus decreased Green Scores for these vehicles. Because of the significant update to GREET 2 battery LCA, we highlight the average impact for BEVs and plug-in hybrid vehicles in table 9.

Table 9. Impact of Changes on Plug-in Electric Vehicles

	BEVs		All Plug-in Vehicles	
	Average EDX (¢/mile)	Average Green Score	Average EDX (¢/mile)	Average Green Score
MY 2018 Results	0.77	64	0.98	57
Cumulative MY2019 Updates	0.88	59	1.02	55

[4] The gamma function for calculating Green Scores applies equally to all vehicles. For a methodological change that applies only to a small subset of vehicles, the resulting change in C-value may be very small. Hence this approach cannot preserve comparability of Green Scores across years for methodological updates that apply to only one vehicle type. In the case of GREET 2 updates, the changes affecting plug-in vehicles are in some part methodological, but we have not adjusted the C-value to reflect the GREET 2 updates.

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