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ACEEE'S GREEN BOOK®

Proposed Updates to ACEEE's Greenercars Rating System for Model Year 2018

American Council for an Energy-Efficient Economy

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This document details our proposed updates for the analysis of model year 2018 cars and light trucks, which will be reflected in the release of ACEEE's Greenercars rankings available at greenercars.org early next year. 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).

Compared to model year 2017, we propose to update power sector emission factors based on GREET 1 2017. We similarly propose to update our analysis of embodied emissions to incorporate GREET 2 2017. This memo also discusses possible changes that we are investigating for future years, but will not implement in MY 2018 ratings.

Changes To be Implemented for MY2018 Greenercars Ratings

INCORPORATE GREET 1 2017 INTO GREENERCARS ELECTRICITY EMISSION FACTORS

For purposes of scoring plug-in vehicles, we calculate emissions related to vehicle charging by using upstream electricity emission factors from Argonne National Laboratory's (ANL) GREET 1 model. Our methodology is based on ANL GREET emission rates for combustion and feedstock emissions for electricity generation based on a current national grid mix and scaled for future years to account for the evolving mix of generation sources.

In prior years, we evaluated and implemented new estimates for power generation emissions from successive updates to GREET. With our MY 2013 scoring, we implemented updates from the GREET 1 2012 model. Beginning with the 2014 update, GREET 1 shows major changes to emissions rates associated with electricity production relative to earlier versions. While some emission factors increased, others declined. When inserted into the Greenercars model, these GREET updates resulted in a net decrease of upstream emissions for electric vehicles, producing an average EV green score increase of about five points. In our preparation for MY 2015 scoring, we were unable to explain the drastic changes in certain emission factors, so we continued use of GREET 1 2012 emission factors We revisited this issue in subsequent years, but the issue persists. Based on a recent literature review, we now have greater confidence that these changes result in improved emissions estimates, as discussed in the following paragraphs. Hence we propose to update upstream emission factors for electricity generation to the newest version of GREET 1 2017, beginning with model year 2018 scoring.

We noted in our MY 2015 methodology memo that PM_{10} and SOx emissions from coal-fired sources had significantly changed between the 2012 and 2014 (and subsequent) versions of GREET. ANL indicated that they had updated SOx emissions in GREET to reflect real-world data published by EPA from continuous emissions monitoring systems (CEMS) installed in the stacks of coal-fired plants. The increase in CO also reflects improved accounting of coal-fired boiler emissions. Changes to CO_2, NOx, and NMHCs generally reflect decreasing emissions and a better characterization of emission factors. To reiterate the scale of this proposed change, Table 1 compares the GREET emission factors from the 2012 and 2017 versions. Electricity generation damage costs for each pollutant, in cents-per-gram, are provided for context.

Table 1. Greenercars Upstream Electricity Emissions from GREET 1 2012 and GREET 1 2017

Pollutant	GREET 1 2012 (g/kWh)	GREET 1 2017 (g/kWh)	Greenercars Damage Cost (¢/gram)
CO	0.125	0.166	0.0004
NMHC	0.058	0.056	0.0047
NOX	0.877	0.358	0.0624
PM_{10}	0.945	0.067	0.5009
SOx	2.092	0.939	0.2942
CO2	633.33	511.46	0.0024

The change in PM_{10} emissions accounts for the largest impact with respect to Greenercars, given the enormous reduction in emissions rates together with the high PM_{10} damage cost. To determine coal mining PM_{10} emissions, GREET uses a weighted average of emission factors for underground and surface mining. GREET 1 2014, as well as subsequent updates, include large reductions in PM10 emissions factors for both surface and underground mining (table 2). Surface mining emissions were updated to reflect EPA's 2011 National Emissions Inventory (NEI) data, and the new underground coal mining emissions are based on a 2012 Australian underground coal mining study (Xstrata 2012). We evaluated the change in underground mining emission factors and found certain irregularities.[1] However, the reductions to surface mining and underground mining emissions estimates were of the same magnitude. There is evidence that sampling methods are prone to inherent deficiencies that can overstate PM emissions by 300 percent or more (Thelen 2010, Buser et al. 2007). Because the updated emission factors appear to reflect the most up-to-date estimates, we plan to accept the surface mine emissions estimates in GREET 2017.

Table 2. Coal Mining PM_{10} Emissions, GREET 1 2012 and GREET 1 2017

	Underground Mining (g/mmBtu)	Surface Mining (g/mmBtu)	Total PM_{10} emissions (g/mmBtu)
GREET 2012	31.2	236.0	175.5
GREET 2017	0.3	11.9	8.3
Share of coal mining	31%	69%	

This ultimately demonstrates an underlying issue with the sampling of non-mobile sources of particulate emissions. In an attempt to understand how these factors could change by multiple orders of magnitude in a few years' time, we reviewed the literature on particulate emissions estimation using traditional sampling methods, including those under EPA AP-42 guidelines. Measurement of particulate matter at sites like open pit mines is especially difficult. The efficiency of samplers is affected by both wind speed and orientation, and measurements are dependent upon proximity to the source of particulates and design of the sampler (Pitts 2005). PM data from the EPA NEI may also fail to adequately represent real-world rates of PM emissions. The NEI is a "composite of data from many different sources," using different data collection methods with some data based on estimates rather than data (EPA 2017a). However, it is currently the de facto source of relevant emissions data.

Based on these considerations, updated emission factors likely reflect a better accounting of real-world PM emissions, so we propose to fully adopt GREET 1 2017 emission factors. Using MY 2017 battery electric vehicles to evaluate this change, we find the update to GREET 1 2017 decreases the Greenercars environmental damage index from 1.053 cents-per-mile to 0.908 cents-per-mile on average.

Table 3. Average BEV Score and Damage Cost Comparison of GREET 1 2012 and GREET 1 2017

	Average EDX (¢/mile)	Upstream Criteria Damage Cost (¢/mile)	Upstream GHG Damage Cost (¢/mile)
GREET 2012	1.053	0.216	0.428
GREET 2017	0.908	0.136	0.363

This change reflects both methodological and real-world changes. Updates to PM and SOx largely reflect methodological changes resulting from new source data or interpretation of sampling results,

[1] The 2012 Australian study used in determining GREET underground coal mining emissions was subsequently updated in 2013 (Xstrata 2013). We evaluated this update which resulted in a PM emission factor that's about 30 times higher. However, this would not reflect our assumption that underground mining PM emissions are inherently lower than above ground. We contacted the mining company who carried out the study, and it appears the new version reflects regulatory changes in Australia rather than a change in sampling methods or emission rates. We plan to maintain GREET 2017 default emission factors.

while the change in CO_2, NOx, and NMHCs are likely reflective of a power grid with a higher share of cleaner fuels and increased renewables.

INCORPORATE GREET 2 2017 EMBODIED EMISSION FACTORS

Greenercars ratings use results from ANL's GREET 2 Vehicle-Cycle Model to estimate the emissions impacts from the manufacturing and assembly, disposal, and recycling (ADR) for a variety of vehicle types. We vary vehicle weight and class for ICEs, and likewise vary vehicle weight, battery weight, and fuel stack component weight, as appropriate, for other vehicle types. This approach results in emissions estimates for each pollutant and vehicle class that are linear in vehicle, battery, and fuel stack weight. The linear formulae are then adjusted to reflect the percentage of emissions that scale with vehicle or component weight, pivoted around the point defined by the default GREET vehicle weight, to pass through the new intercept.

Greenercars currently uses the 2012 version of the GREET 2 model estimates. In prior years, we evaluated the subsequent updates to the GREET 2 model (see appendix). The vehicle-cycle model uses GREET 1 electricity generation emission factors to account for electricity use in the manufacturing process. As with the upstream electricity emissions discussed in the prior section, we did not update Greenercars to reflect changes to the GREET 2 model, maintaining use of GREET 2 2012. Because we are now proposing to update power sector emissions factors to GREET 1 2017, we also propose to update to GREET 2 2017 in our embodied emissions calculations.

The net result of all changes to the embodied emission formulae is a 0.12 ¢/mile reduction of the embodied emissions component of the EDX, on average. This results in the total average EDX decreasing by about six percent (table 4). Similar to the conclusion regarding GREET 1, updates to GREET 2 incorporate several changes representing a mix of real-world and methodological updates.

Table 4. Average Damage Cost Comparison of GREET 2 2012 and GREET 2 2017

	Total EDX (¢/mile)	Embodied Criteria Pollutants (¢/mile)	Embodied Greenhouse Gas (¢/mile)
GREET 2 2012	1.76	0.21	0.14
GREET 2 2017	1.65	0.13	0.10

COMBINED IMPACT OF METHODOLOGY CHANGES

To evaluate the impact of the above methodology changes on average EDX and Green Score, we applied them to the MY 2017 vehicle data. We compare results from the MY 2017 Greenercars analysis with the changes to GREET 1 electricity emissions, and the changes to GREET 2 embodied emissions.

Greenercars converts a vehicle's total damage cost (in cents per mile) to a Green Score (a value 0 to 100) using a gamma function (Vaidyanathan et al. 2016). When we update our methodology, we determine whether the resulting change in EDX is the result of a real-world change in lifecycle emissions, or purely from the change in methodology. In the latter case, we adjust the gamma function to ensure that Green Scores are comparable across model years and do not fluctuate due to methodology changes. In the case of the update to GREET 2017, we assume that the changes to damage cost are equal parts real-world and methodological changes, and adjust the mapping to Green Scores accordingly.

The update to GREET 1 2017 alone increased the average Green Score across all vehicle types from 39.7 to 39.8, while Green Scores of BEVs increase by 4.4 points on average. We note that even by adjusting the gamma function to maintain scoring consistency for all vehicles, we may be inappropriately optimistic in our scoring of plug-in electric vehicles. However, based on the assumption that GREET uses the most up-to-date information on power sector emissions, we believe the increase in Green Score is valid.

It's difficult to determine with precision the share of updates to GREET that is purely methodological. We find that the majority of the change between the 2012 and 2017 versions of both GREET models is due to changes in electricity emissions discussed in the previous section. For example, GREET 2 estimates that vehicle cycle PM_{10} emissions for a 3,183 lb. gasoline vehicle (the default in GREET 2017) decreased by over 70% as the result of the aforementioned updates to upstream electricity emissions.

To maintain comparison of scores between years, we propose to modify the gamma function to reflect an estimated 50% methodological change regarding both updates. We will determine whether this assumption requires modification based on comments and additional research before scoring MY 2018 vehicles.

We calculated a new gamma function for each scenario as discussed in each of the prior sections. This adjusts the calculation of Green Score from a vehicle's EDX. For this calculation, we previously estimated that the update to electricity emissions represents 50% real-world impacts, and the update to embodied emissions also representing 50% real-world impacts. The remaining changes are methodological, which is absorbed into the new C-value calculation to allow for comparison of Green Scores from one year to the next. Table 5 highlights the combined impact of the changes on average EDX and Green Score for all vehicles, reflecting the respective changes to the C-value.

Table 5. Overall Impact of Changes on Average EDX and Green Score

	All Vehicles		Cars		Light Trucks	
	Average EDX (¢/mile)	Average Green Score	Average EDX (¢/mile)	Average Green Score	Average EDX (¢/mile)	Average Green Score
MY 2017 Results	1.76	39.7	1.62	42.4	1.93	36.5
GREET 1, GREET 2 2017 updates	1.65	40.7	1.50	43.8	1.82	37.1

The average impact for BEVs and plug-in hybrid vehicles is highlighted in table 6.

Table 6. 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 2017 Results	1.08	55.3	1.20	52.3
GREET 1, GREET 2 2017 updates	0.80	62.8	0.95	58.5

The largest impact on all vehicle types results from the update to embodied emissions. GREET 1 updates affect the accounting of emissions from vehicle charging, but also of embodied emissions. As a result, the impact of updated GREET 1 2017 electricity emission factors accounts for the majority of the change in EDX for plug-in electric vehicles. As mentioned before, we believe these updates represent the most current understanding of the accounting of these emissions sources. The increase in score for electric vehicles is large and, as a result, we request comment on the increase in scores.

Changes to be investigated for future editions of Greenercars

UPDATING HEALTH DAMAGE COSTS

New research and a variety of models that account for damage costs of emissions present an opportunity to determine if damage costs in Greenercars warrant an update. EPA's Co-Benefits Risk Assessment (COBRA) model, among others, can be used to extract damage costs associated with light-duty vehicles and other sources relevant to the Greeenercars methodology. We are looking for comments on whether health damage cost estimates for mobile source emissions have changed significantly in recent years.

EMBODIED EMISSIONS FOR VEHICLES WITH LIGHT-WEIGHT MATERIALS

Current methodology treats all models as having traditional material composition. We calculate embodied emissions based on the GREET 2 characterization of vehicles with a traditional material composition. GREET 2 is also capable of lifecycle calculations for vehicles composed of a mix of traditional and lightweight materials. We currently cannot differentiate between vehicles based on their use of non-traditional material, as relevant data on a per-model basis is unavailable. In recent years, a growing number of vehicles contain a significant amount of lightweight material. Most notably, the current F-150 makes extensive use of aluminum in its body construction. The BMW i3 and i8, both which score well in Greenercars, make use of carbon fiber-reinforced plastics. Recent reports claim that General Motors is planning a carbon fiber bed on premium versions of its full-size pickup trucks (Colias 2017).

Some recent research finds that the energy and emissions associated with producing lightweight materials are typically higher than steel and other traditional materials (Dai et al. 2016). Such research findings are reflected in GREET 2. To demonstrate how the use of lightweight materials could affect a vehicle's Green Score, we evaluate all 2017 models of the Ford F-150, given its significant use of aluminum in the vehicle body. We first scored all models of the F-150 using updated GREET 2017 embodied emission factors as discussed above. We then obtained emission factors using GREET 2's default material composition for lightweighted ICE pickup trucks. The GREET characterization of a lightweighted pickup truck compares to one of traditional materials with a decreased vehicle weight and an increased percentage of aluminum in the body. Based on a literature review, the material composition of the F-150 appears to be a close approximation to the default GREET 2 lightweight truck material composition.

The average Green Score of F-150 models using GREET lightweight material assumptions is 2.2 points lower than when scored assuming a traditional material composition. This reflects a 7% increase in per-mile damage costs (EDX).

Table 7. 2017 Ford F-150 scores. Traditional materials versus aluminum-intensive design

	Average GS	Average EDX	Highest scoring model	Lowest scoring model
F-150, traditional	33.9	2.07	41.1	25.0
F-150, aluminum	31.7	2.21	38.6	23.4

The result shows that based on GREET assumptions, a vehicle scored to reflect a high percentage of aluminum will score lower than one made with traditional materials. As commenters noted last year, greater lightweighting efforts have increased the number of vehicles with alternative materials.

However, as commenters also noted, data regarding specific lightweighting on a per-model basis does not exist. We request additional comments regarding the handling of embodied emissions for lightweighted vehicles.

Emission Standards vs Real World Emissions using EPA MOVES2014a

This section was included in our MY 2017 methodology memo reflecting analysis which we performed using the November 2016 update of EPA MOVES2014a. Our analysis in this section has not been updated to reflect any subsequent updates to MOVES. We include this section again and appreciate additional comments.

Our current approach of using a vehicle's emissions certification to estimate in-use criteria pollution reflects the lack of up-to-date data on real-world in-use vehicle emissions and how they vary by bin certification, vehicle type, and/or fuel type. While vehicle-specific certification data is available from EPA, certification tests will not fully capture emissions in real-world conditions.

For MY 2018, about 90 percent of available models listed in the data provided by EPA are certified to LEV III or Tier 3. Both programs transitioned to a combined NMOG + NOx standard. For gasoline vehicles, we assume that 2/3 is attributable to VOC and 1/3 to NOx, per EPA estimates (EPA 2014). For diesel vehicles, we similarly follow EPA guidance that 100% is attributable to NOx. We are exploring the use of EPA's MOVES to generate real-world emissions estimates to replace the current approach. This could provide more realistic emissions factors based on the type of vehicle and how it's operated. However, MOVES was not designed to produce bin-specific emissions rates necessary for the Greenercars methodology.

We ran MOVES to compare real-world emissions to certified emissions under Tier 3. MY 2025 vehicles will, on average, certify to Tier 3 Bin 30, implying NMOG + NOx value of 30 mg per mile. Fuel types were restricted to gasoline, diesel, E-85, hybrid, and BEVs. We analyzed running and start tailpipe emissions to compare with the respective vehicle tailpipe certification bins. Table 8 shows the results below.

Table 8. MOVES results for light-duty vehicles, MY 2025, in comparison with Tier 3 Certifications

Emission Source	NMOG	NOx	NMOG + NOx	PM10	CO	HCHO
		mg/mi			g/mi	mg/mi
MY 2025 Cars						
Running Exhaust	1.1	11.2	12.3	1.3	0.4	0.0
Start Exhaust	28.5	18.3	46.8	0.4	0.3	0.3
Total	29.6	29.5	59.2	1.7	0.7	0.3
MY 2025 Light Tucks						
Running Exhaust	1.3	13.7	15.1	1.7	0.4	0.0
Start Exhaust	24.5	16.4	40.9	0.5	0.2	0.3
Total	25.8	30.2	56.0	2.2	0.7	0.3
MOVES MY2025 Fleet Average			57.9	1.9	0.7	0.3
Tier 3 Bin 30			30	3	1	4
Tier 3 Bin 70			70	3	1.7	4

Table 8 shows that MOVES predicts the MY 2025 fleet average emissions to be almost twice the average certification value (Bin 30) for NMOG + NOx emissions, while the predicted values for PM, CO, and formaldehyde are below the certification value. We found higher NMOG + NOx emissions for cars than for light trucks. This appears to be due to greater start exhaust emissions for cars (table 9), as MOVES input data shows a greater number of starts for cars than for trucks (EPA 2016b). However, we found that average emission rates for trucks are greater than cars when including other MOVES emissions processes.[2]

Table 9. Vehicle starts, as used in MOVES

Source Type	Weekday (starts per day)	Weekend (starts per day)
Cars	5.89	5.30
Trucks	5.80	5.06

More analysis is required to determine how these real-world emissions estimates from MOVES can apply to vehicles certified to the various Tier 3 bins.

We request comments on the possibility of using MOVES2014a to determine emission factors for future versions of Greenercars, and whether such an approach can better capture real-world emissions and improve the fairness and accuracy of Greenercars results.

[2] We have not yet researched how certain emissions sources are treated in MOVES. MOVES accounts for emissions processes not included in Greenercars, such as those from brakes, tires, etc. We will explore these as appropriate.

Appendix

GREET 2 MODEL CHANGES

GREET 2 2014 (ANL 2014)

1. Added new vehicles for both baseline and lightweighted models, with different material compositions
2. Added carbon fiber and magnesium production assumptions
3. Added additional cathode materials and composition data for Li-ion batteries including lithium cobalt oxide, lithium nickel manganese cobalt oxide, lithium manganese oxide and lithium iron phosphate

GREET 2 2015 (ANL 2015)

1. Updated life-cycle pathways and emissions estimates for aluminum
2. Updated anode materials data for Li-ion battery anodes, including graphite and metallic lithium
3. Detailed update to the material composition of baseline pickup trucks
4. Updated vehicle powertrain material composition

GREET 2 2016 (ANL 2016)

1. Updated vehicle weights and material composition by component based on latest ANL cradle-to-grave study
2. Updated composition of fuel cell powertrains and hydrogen storage
3. Updated recycled content for magnesium, and quantity of SF6 and HFC-134a used in magnesium's manufacture

GREET 2 2017 (ANL 2017)

1. Added lifecycle inventory data for the production of cathode material for batteries
2. Updated energy and water consumption for Li-ion battery manufacturing
3. Updated energy consumption and material efficiency for steel and aluminum stamping

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