MOVES

Motor Vehicle Emission Simulator

EPA Plans for Electric Vehicles Modeling in MOVES4

July 20, 2023

MOVES4 public webinar

Overview

- MOVES4 will have improved capability of modeling electric vehicles (EVs):
  - Improved EV base energy rates
  - Added electricity as a fuel type for heavy-duty source types
    - This includes Battery Electric Vehicles (BEV) and Fuel Cell Electric Vehicles (FCEV)
  - Added temperature effects for EVs
  - Added battery efficiency by age adjustments
  - Added charging efficiency adjustments
  - Non-zero national default EV fleet fractions

Overview

- User inputs:
  - As with previous versions of MOVES, the Alternate Vehicle and Fuel Technology (AVFT) input table can be used to model local variations in fuel type distributions
  - MOVES4 will come with an AVFT Tool to assist modelers with preparing this input

- No change planned for how MOVES models hybrid (HEV) or plug-in hybrid (PHEV) vehicles
  - Modeled as internal combustion engine (ICE) vehicles

EV ENERGY RATES

Light-Duty EV Energy Rates

- Passenger car EV energy rates based on results from EPA's ALPHA (Advanced Light-Duty Powertrain and Hybrid Analysis) tool
  - Nine BEVs representative[1] of the 2019 fleet were simulated in ALPHA using:
    - Three repeats of the EPA Urban Dynamometer Driving Schedule (UDDS) and Highway Fuel Economy Driving Schedule (HWFET) cycles
    - Two additional sets of drive cycles in order to cover the high power/high speed operating modes
  - Calculated average energy rates by MOVES operating mode using 2019 sales weighting
- EV rates for light- and medium-duty trucks (up to class 3) scaled from car rates due to lack of data
  - Assuming that energy used during vehicle operations and energy gained from regenerative braking scale linearly with vehicle mass

1. BMW i3, Chevy Bolt, Fiat 500e, Honda Clarity (BEV), Nissan Leaf, Tesla Model 3, Tesla Model S, Tesla Model X, and VW e-Golf

Heavy-Duty EV Energy Rates

- HD EV energy rates are modeled using an Energy Efficiency Ratio (EER):
  - EV energy consumption is calculated relative to diesel energy consumption using EER values based on a literature review

$$\text{Energy}_{\text{EV}} = \frac{\text{Energy}_{\text{diesel}}}{EER}$$

  - EERs vary by source type and BEV or FCEV
- Added shore power (plugging in) hotelling operating mode for long-haul combination trucks
- Limitations:
  - Assuming that relative power demand across operating modes is the same between ICE and EV
  - While regenerative braking is included in the estimation of EERs, it is not explicitly modelled for heavy-duty EVs like it is for light-duty

EER Literature Review Sources:

- CARB
- NREL Transit Buses, Delivery Trucks, Tractors
- Altoona
- GREET
- National Center for Sustainable Transportation
- Kotz et al.
- Gao et al.
- Zhao et al.
- Scania
- CalHEAT

EV ADJUSTMENTS

Temperature Adjustment for EV

- Motivation:
  - Heating and air conditioning increase EV energy consumption
  - Temperature also affects resistance in the drive train and electrical components
- Low temperature:
  - Heating is important because EVs cannot scavenge waste heat from the engine like ICE vehicles
  - Adjustment in MOVES is based on American Automobile Association (AAA) study:[2]
    - Tested several EV passenger cars on a chassis dynamometer at room temperature, 20°F, and 95°F
    - Covers a variety of heating and cooling technologies, including both heat pumps (BMW i3s and Nissan Leaf) and resistive heaters (Chevrolet Bolt, Tesla Model S, and Volkswagen e-Golf)
- High temperature:
  - MOVES already models air conditioning adjustments for light-duty vehicles of all fuel types
  - Added heavy-duty EV temperature adjustment at high temperature, based on the AAA study

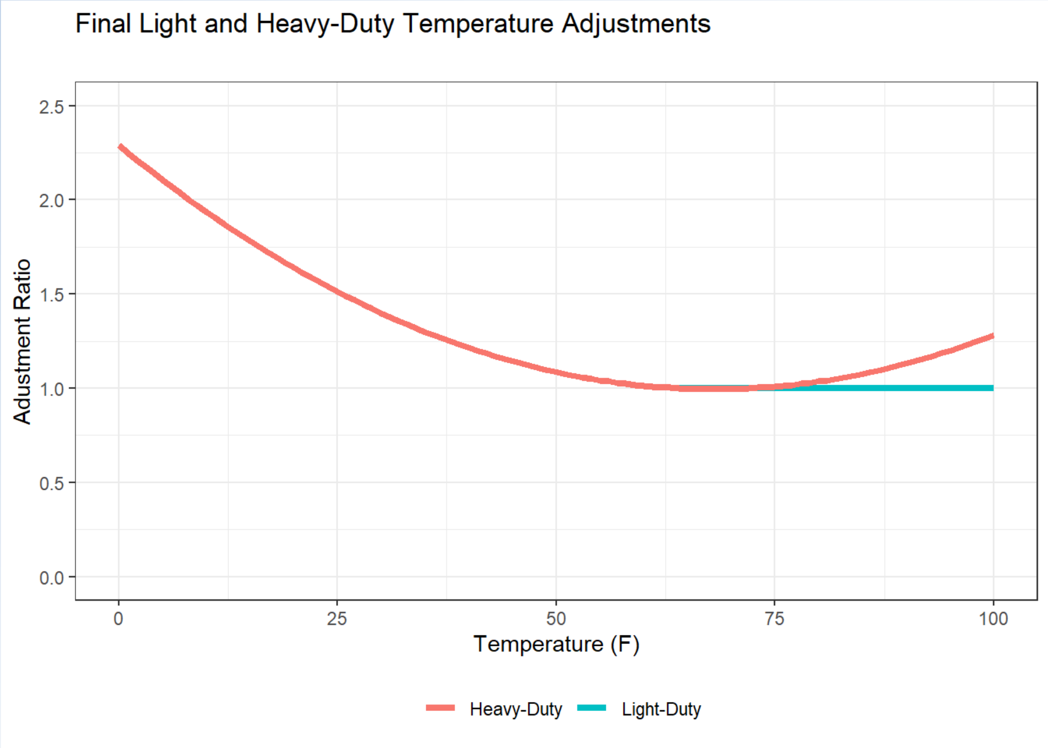
2. American Automobile Association, Inc. (2019). AAA Electric Vehicle Range Testing. AAA proprietary research into the effect of ambient temperature and HVAC use on driving range and MPGe. American Automobile Association, Inc.

Temperature Adjustment for EV

- Modeled in MOVES using the same quadratic equation used for other multiplicative temperature adjustments:

$$Adjustment = 1.0 + A \times (t - 72) + B \times (t - 72)^2$$

- *A* and *B* terms were calculated for both LD and HD EVs from the AAA study
- The results of this adjustment compare well with other studies:
  - Environment and Climate Change Canada (ECCC) performed on-road, real-world testing of a 2018 Chevrolet Bolt in January and July of 2019
  - In 2018, Liu et al. collected energy consumption data from 68 passenger car EVs being driven across Japan, at a wide range of ambient temperatures
  - Henning et al. published a paper which included observational data from both battery electric and fuel cell urban buses. The data was collected by eight transportation agencies in North America, ranging from California to Minnesota



EV Battery Efficiency

- Battery efficiency in MOVES covers charger-to-drivetrain losses
  - Yang et al.[3] suggests internal resistance (R) increases as batteries age, increasing energy consumption (E):

$$\Delta E = E \times \frac{1}{1 + \Delta R}$$

  - However, there is substantial uncertainty about how batteries age beyond 10 years:
    - Do they continue to deteriorate? Or do they improve due to battery replacement under warranty? etc.
    - We assumed overall battery efficiency doesn't change beyond the first 10 years (similar to how we model criteria pollutant emission rate deterioration for ICE vehicles)

Age Group	Battery Efficiency
0 – 3	**0.95**
4 – 5	**0.903153**
6 – 7	**0.874407**
8 – 9	**0.847435**
10 – 14	**0.828273**
15 – 19	**0.828273**
20+	**0.828273**

3. Yang, et al. (2018). Predictive modeling of battery degradation and greenhouse gas emissions from U.S. state-level electric vehicle operation

EV Charger Efficiency

- Charger efficiency in MOVES covers wall-to-charger losses
  - Charger efficiency in MOVES is based on recommendations from internal and external experts[4] and literature review[5 6 7]
- We evaluated the combined efficiency against Altoona bus program and the results are comparable
- Limitations:
  - Use same values for all source types, regclasses and model years
  - Technology is evolving rapidly

Age Group	Charger Efficiency	Battery Efficiency	Combined Efficiency
0 – 3	**0.94**	0.95	0.893
4 – 5	**0.94**	0.903153	0.848964
6 – 7	**0.94**	0.874407	0.821943
8 – 9	**0.94**	0.847435	0.796589
10 – 14	**0.94**	0.828273	0.778577
15 – 19	**0.94**	0.828273	0.778577
20+	**0.94**	0.828273	0.778577

4. Altoona Bus Research and Test Center, Penn State College of Engineering
5. Tan, et al. (2014). Bidirectional battery charger for electric vehicle
6. Kreiger and Arnold. (2012). Effects of undercharge and internal loss on the rate dependence of battery storage efficiency
7. Apostolaki-Iosifidou, et al. (2017). Measurement of power loss during electric vehicle charging and discharging

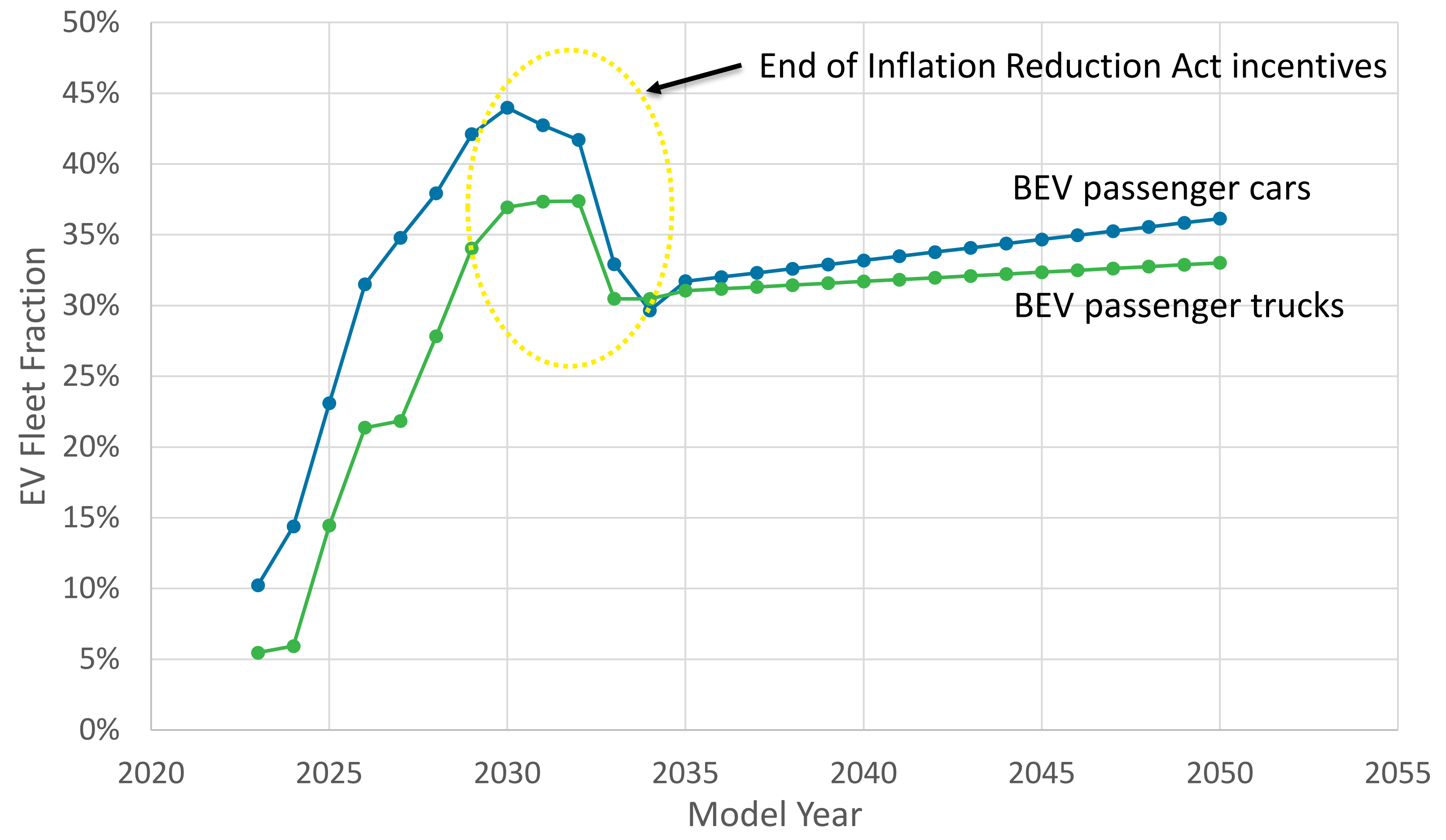
NATIONAL DEFAULT EV FLEET FRACTION

Light-Duty
National Default EV Fleet Fraction

- LD BEVs:
  - Pre-MY2023
    - Based on 2022 EPA Automotive Trends Report
  - MY2023–MY2050
    - Based on LD EV costs and consumer preferences as modeled in EPA OMEGA (Optimization Model for reducing Emissions of Greenhouse Gases from Automobiles) model[8]
    - Includes the impact of incentives included in the Inflation Reduction Act
  - MY2051–MY2060
    - Same growth rate as from MY2049 to MY2050
- Class 2b BEVs:
  - Based on OMEGA outputs and an analysis of states that have adopted California Advanced Clean Trucks

8. Output based on *Proposed Rule: Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles*, using the business-as-usual baseline

Light-Duty
National Default EV Fleet Fraction



Heavy-Duty
National Default EV Fleet Fraction

- Pre-MY2020 based on:
  - IHS 2014 data (pre-MY 2014)
  - IHS 2020 data (MY2014–MY2019)
  - EPA compliance data

- MY2020+ based on:
  - An analysis of states that have adopted California Advanced Clean Trucks
  - An analysis of Inflation Reduction Act incentives
  - In general, assume that long-haul source types are FCEV and short-haul source types are BEV

AVFT TOOL

AVFT Table

- The AVFT (Alternate Vehicle Fuel and Technologies) table allows modelers to specify local distributions of the following fuel and technology types by source type and model year:
  - Gasoline
  - Diesel
  - CNG
  - Flexible Fuel (gasoline or E-85)
  - Battery Electric
  - Fuel Cell Electric

AVFT Tool

- Helps modelers project local future fuel type distributions based on projected national trends
- Requires local historic fuel type distributions as input data
  - Typically, this is based on local vehicle registration data
- The tool also gap-fills local historic data if necessary
- Output is a spreadsheet that plots the results and can be imported into user input databases
- EPA will provide guidance and training on how to use this new tool after MOVES4 is released

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SUMMARY

Summary

- MOVES4 will significantly improve the capability to model EVs:
  - Improves LD base EV energy rates
  - Adds capability to model HD EVs
  - Improves EV energy rate adjustments
  - Adds national default EV population
  - Includes a tool to help model local conditions using the AVFT table
- Current and Future Work for MOVES
  - Improve our understanding of brake and tire wear from EVs
  - Collect more data on BEV and FCEV
    - Partnering with NREL to gather both real measurements and simulated data, capturing various factors which influence vehicle power demands

APPENDIX

MOVES Source Types and Regulatory Classes

Source Types

ID	HPMS ID	Name
11	10	Motorcycle
21	25	Passenger Car
31	25	Passenger Truck*
32	25	Light Commercial Truck*
41	40	Other Buses
42	40	Transit Bus
43	40	School Bus
51	50	Refuse Truck†
52	50	Single Unit Short-haul Truck†
53	50	Single Unit Long-haul Truck†
54	50	Motor Home†
61	60	Combination Short-haul Truck†
62	60	Combination Long-haul Truck†

* Light-duty: 4 wheels *and* GVWR ≤10,000 lbs
† Heavy-duty: 6+ wheels *or* GVWR >10,000 lbs

Regulatory Class

ID	Name	Description (see upcoming report *Population and Activity of Onroad Vehicles in MOVES4* for more information)
10	MC	Motorcycles
20	LDV	Light Duty Vehicles
30	LDT	Light Duty Trucks
41	LHD2b3	Chassis-certified Class 2b and 3 Trucks (8,500 lbs < GVWR ≤ 14,000 lbs)
42	LHD45	Class 4 and 5 Trucks (14,000 lbs < GVWR ≤ 19,500 lbs) & “incomplete” Class 3 Trucks
46	MHD67	Class 6 and 7 Trucks (19,500 lbs < GVWR ≤ 33,000 lbs)
47	HHD8	Class 8a and 8b Trucks (GVWR > 33,000 lbs)
48	Urban Bus	Urban Bus (see CFR Sec 86.091_2)
49	Gliders	Glider Vehicles (see EPA-420-F-15-904)

GVWR = Gross Vehicle Weight Rating