MOVES
Motor Vehicle Emission Simulator

MOVES3 Fuel Consumption Evaluation

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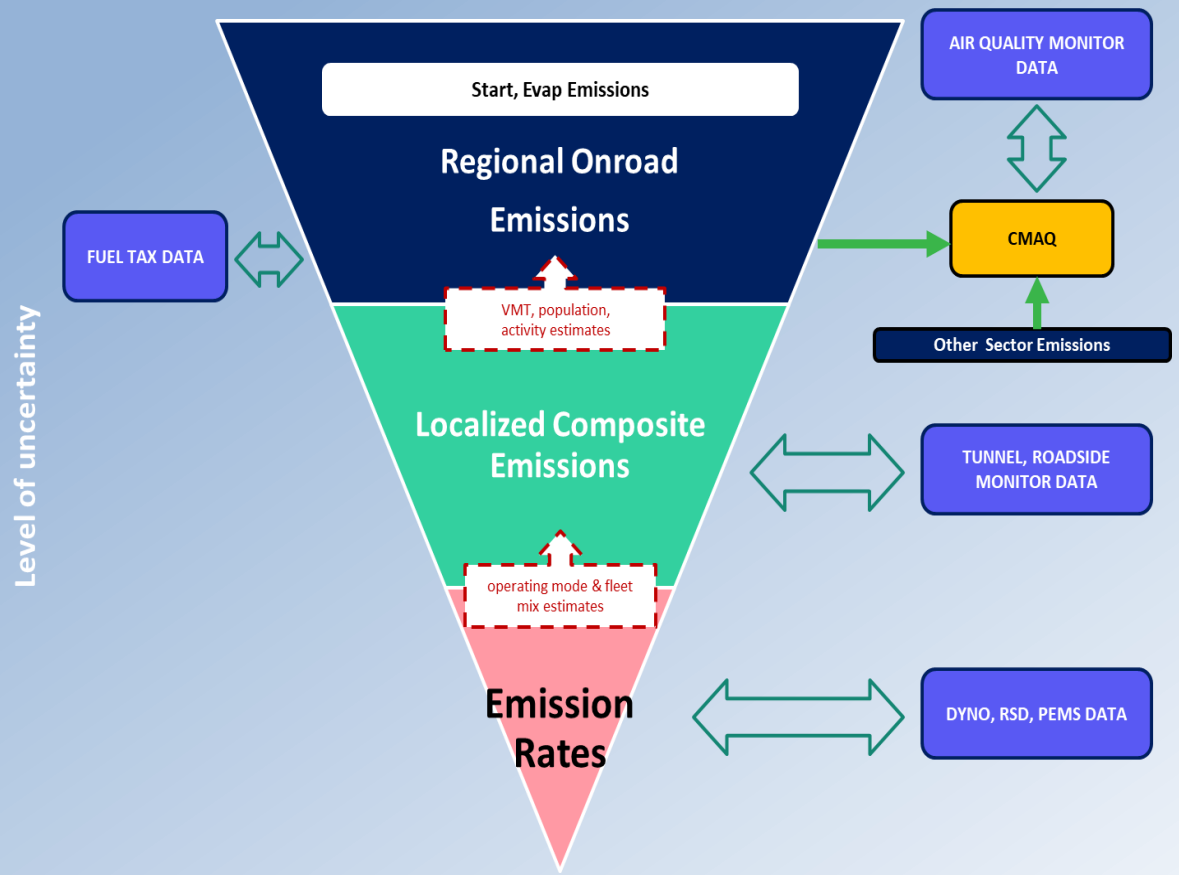
Outline

- Introduction
- U.S. Highway Fuel Consumption
  - Gasoline
  - Diesel
- VMT Comparison
- MPG Comparison with SmartWay
- Summary

Introduction

Background



Multiple approaches needed to fully assess MOVES performance, including:

- Evaluate fuel consumption
- Compare results of air quality modeling using MOVES inputs with monitor data
  - Such as current EPA EQUATES project
- Compare MOVES emission rates with alternate data sources
  - See, for example, March 2017 work group presentation

Overview

- Evaluating MOVES is challenging and requires a variety of approaches.
- One approach to assess MOVES fidelity to real-world vehicle activity is to compare total gasoline and diesel fuel consumption estimated by FHWA with that estimated by MOVES.
- Analysis goal: comparison of MOVES3 gasoline and diesel fuel consumption with Federal Highway Administration (FHWA) estimates & MOVES2014b for historical years (CY2005 – 2018)
  - MOVES "bottom-up" estimates of fuel consumption compared to FHWA's "top-down" fuel sales estimates
  - Impacts of MOVES model update on fuel consumption estimates

Caveats on This Work

- Disparity in the approaches:
  - Fuel sales provides a “macro-scale top down” check on “bottom up” modeling approaches such as in MOVES.
- An “apples-to-apples” comparison is difficult since uncertainties exist on both ends:
  - Accuracy of modeled emissions are determined by the quality of modeling assumptions and input data. There is a constant need to update them as better information becomes available.
  - Available comparison data is scarce and has its own limitations related to data collection & processing method.
  - More details on limitations on slide 10.
- This presentation is intended to:
  - Inform the workgroup members of the current status of MOVES3 fuel consumption estimates.
  - Promote discussion about potential future improvements.

MOVES Runs for Fuel Consumption

- Model: MOVES3.0.1 & MOVES2014b (2 most recent public versions)
- Onroad, Default (a.k.a. “National”) scale
- Inventory mode, “Nation” as a region (50 states + D.C. – PR/VI)
- Calendar years: 2005, 2007, 2009, 2011 thru 2019
- All months, Weekdays & Weekends, All hours
- All source types & fuel types*
- Hourly pre-aggregation
- Output^: Total energy consumption (and corresponding CO_2), Vehicle Miles Traveled (VMT), Vehicle Populations (VPOP)

* Some sourcetype+fueltype combinations were excluded in post-processing step for diesel fuel consumption calculation.
^ MOVES does NOT output “fuel volumes” directly.

Conversion of Total Energy Output to Fuel Volumes*

- Use average fuel energy content values below

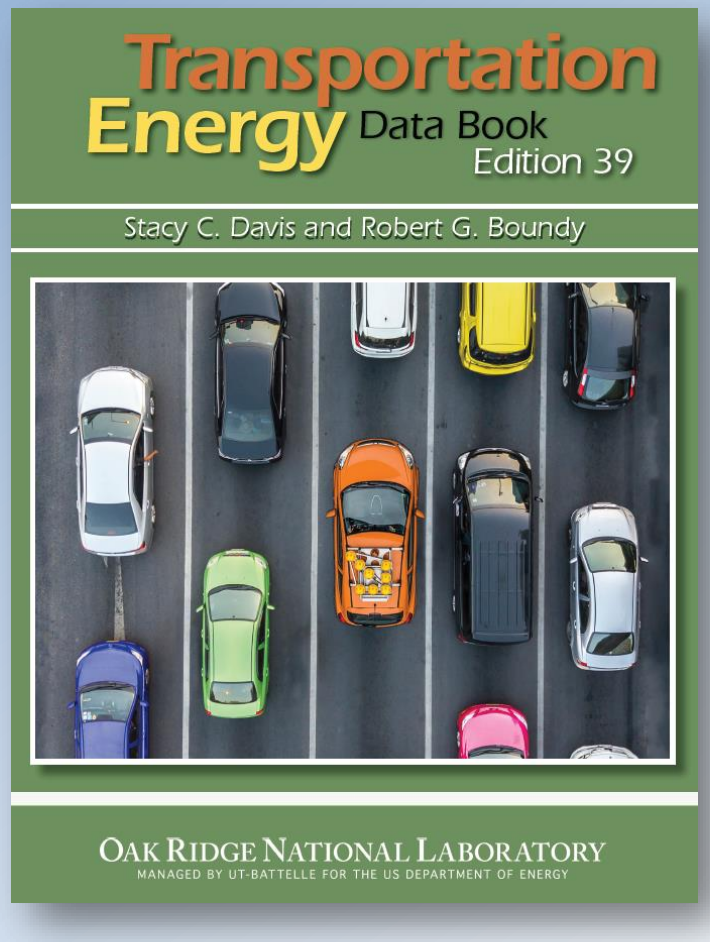
Fuel	Lower Heating Value (KJ/gram)	Density (Kg/gallon)	Energy Content (MJ/gallon)
Gasoline	44.0	2.8	124
Diesel	43.2	3.2	137

- For diesel fuel consumption calculation, exclude Transit Bus (42), School Bus (43), and Refuse Truck (51) source types from MOVES results
  - Because FHWA estimates exclude "public" vehicles

* Same approach was used for MOVE2010/2014a validation.

FHWA Highway Statistics Data for Comparison

- Transportation Energy Data Book Edition 39 – Released February 2021



  - Table 2.12: Highway Usage of Gasoline and Diesel, CY 1973–2018 (Compilation of FHWA MF-27 tables)
  - Table 3.9: Shares of Highway Vehicle-Miles Traveled by Vehicle Type, CY 1970–2018 (Compilation of FHWA VM-1 tables)

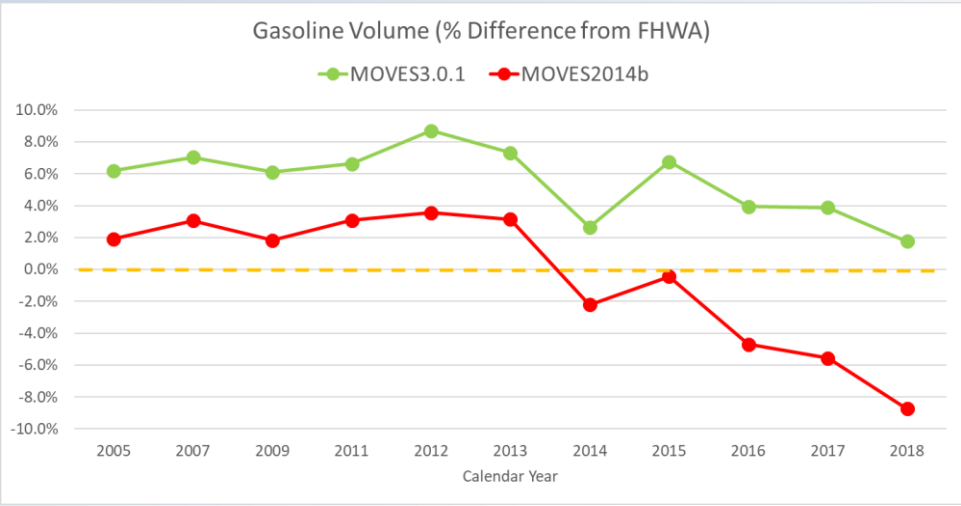
Limitations

- FHWA
  - Potential inaccuracies in state-provided fuel tax collection data
  - Methodology employed by FHWA to allocate between highway and off-road fuel use
- MOVES
  - Conversion of total energy to fuel consumption
  - Attempt to replicate FHWA “public vehicles”
  - Uncertainties in activity estimates and fleet characterization including allocation
  - Energy rates for pre-MY2010 light-duty trucks and heavy-duty vehicles are based on limited data

U.S. Highway Gasoline Fuel Consumption

US Gasoline Consumption

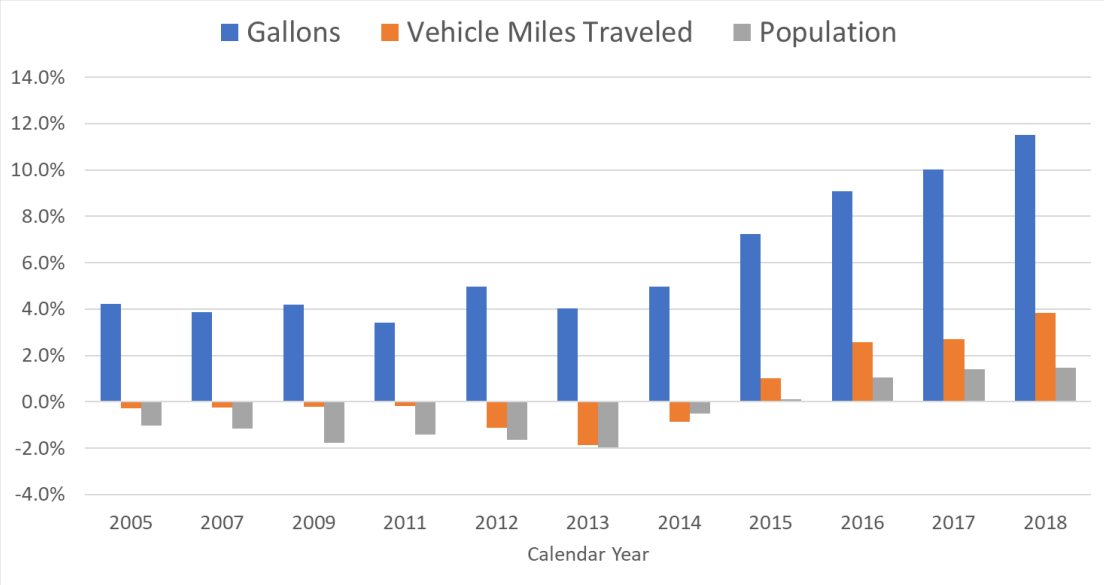
Calendar Year	Gasoline – Highway Use in Billion Gallons (and % Differences)				
	FHWA	MOVES3.0.1		MOVES2014b	
2005	135.2	143.6	6.2%	137.8	1.9%
2007	135.4	144.9	7.0%	139.5	3.1%
2009	132.9	141.0	6.1%	135.3	1.8%
2011	131.5	140.2	6.6%	135.6	3.1%
2012	130.9	142.3	8.7%	135.6	3.6%
2013	131.3	140.9	7.3%	135.4	3.2%
2014	136.5	140.1	2.7%	133.5	-2.2%
2015	132.2	141.1	6.8%	131.6	-0.4%
2016	136.3	141.7	4.0%	129.9	-4.7%
2017	135.3	140.5	3.9%	127.8	-5.6%
2018	137.2	139.6	1.8%	125.2	-8.8%



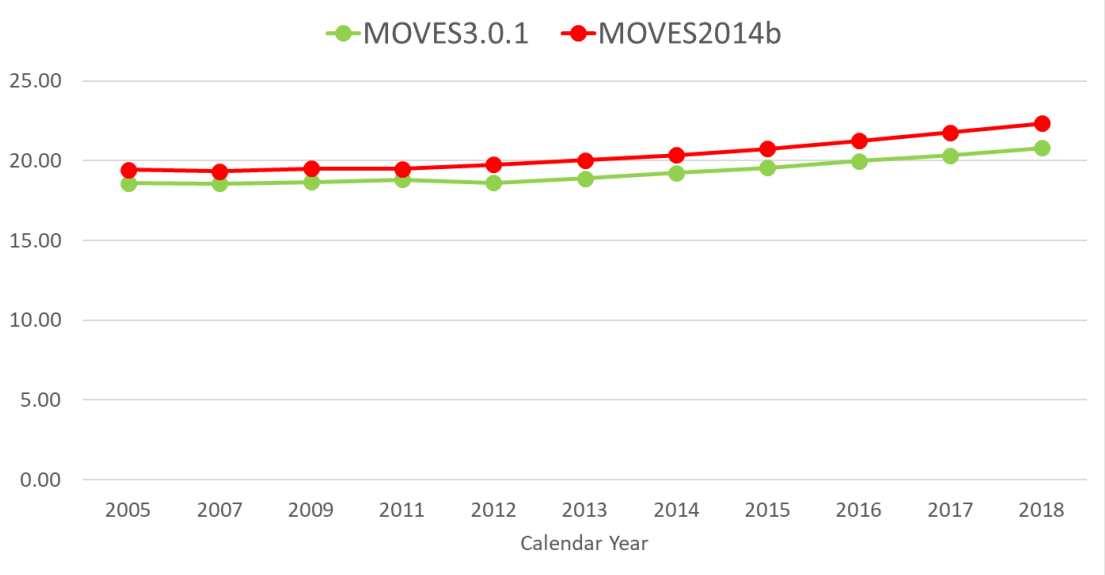
- MOVES3.0.1 estimates are higher than FHWA & MOVES2014b
- Comparison improves for recent years

US Gasoline:
Impacts of MOVES Update

Summary of % Changes (MOVES3.0.1 – MOVES2014b)



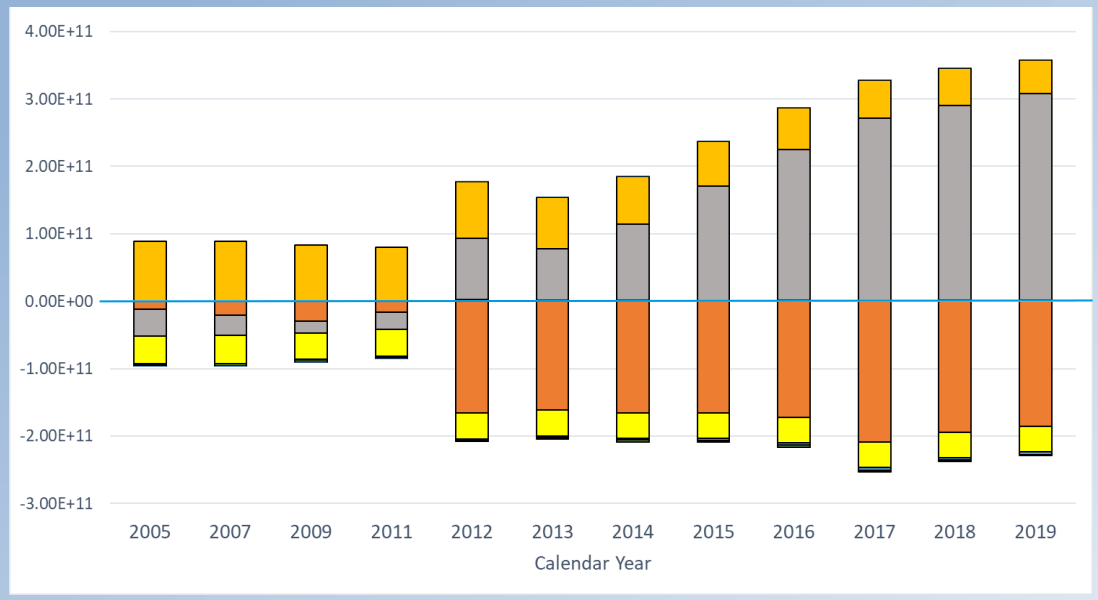
Miles Per Gallon (MPG) Comparison

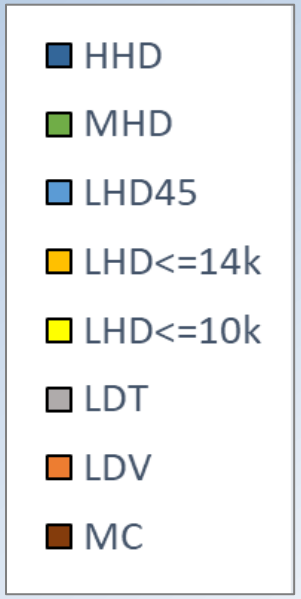


- In MOVES3, compared to MOVES2014b
  - Gasoline fuel consumption increases more than VMT and VPOP changes
  - That is, average gasoline fleet MPG becomes lower
  - However, the MOVES LD energy rates did not change for the years considered here

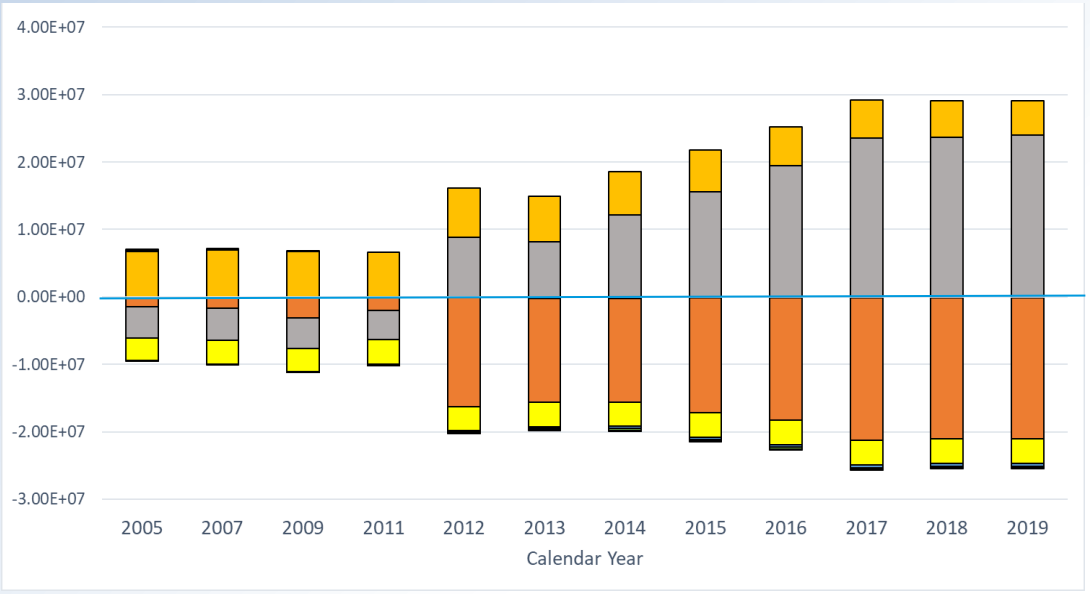
US Gasoline:
Impacts of MOVES Update

VMT differences (MOVES3.0.1 – MOVES2014b) **by Regulatory Class**





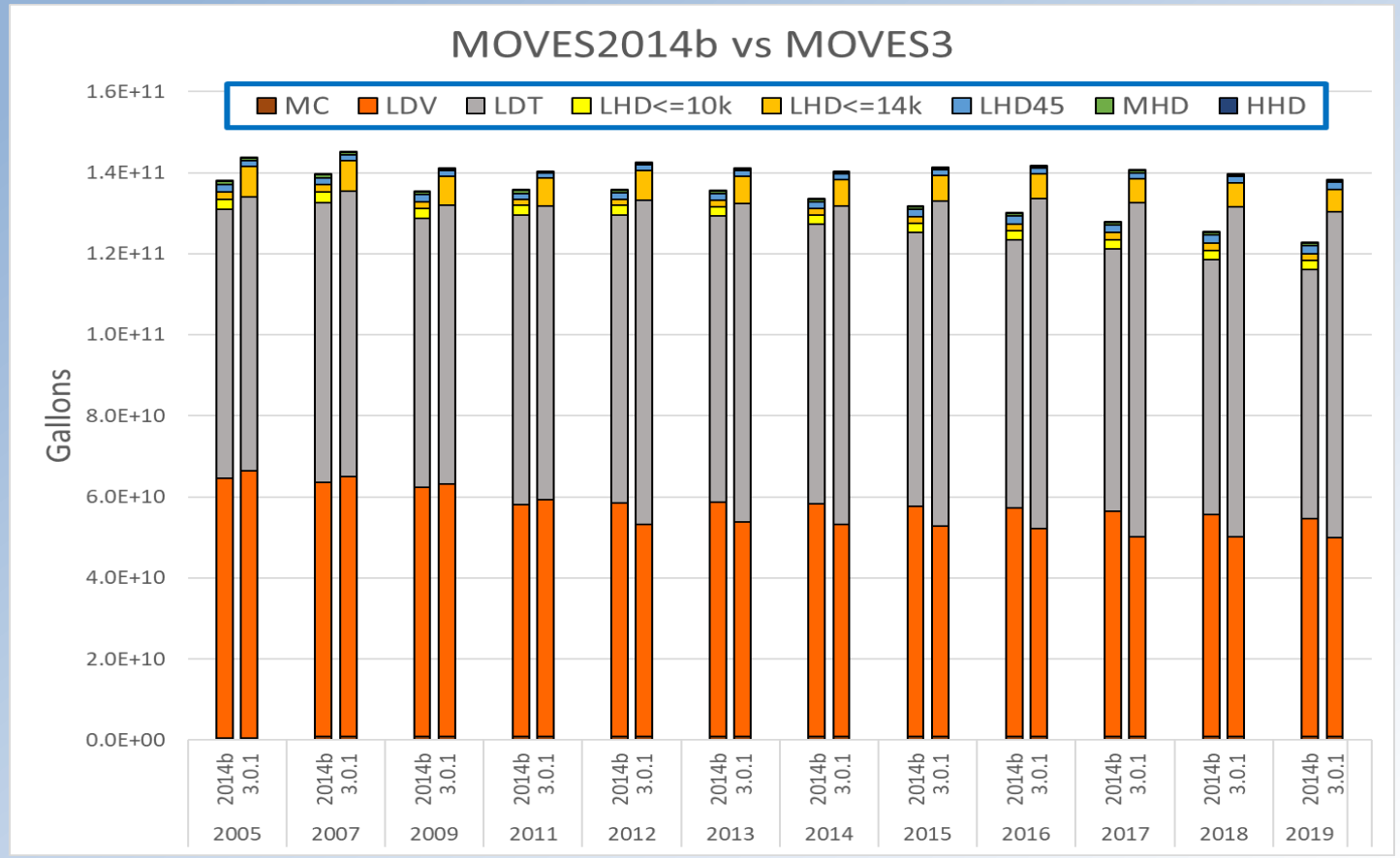
VPOP differences (MOVES3.0.1 – MOVES2014b) **by Regulatory Class**



- Compared to MOVES2014b, MOVES3.0.1 has different LD fleet mix:
  - Fewer "Light Duty Vehicles (LDV)" and shift to heavier truck classes
- Net VMT and VPOP changes are relatively modest:
  - Within 4% and 2% ranges, respectively, across the CY's

US Gasoline:
Impacts of MOVES Update

Gasoline Volume Comparison by Regulatory Class



Regulatory Class - regClassID

ID	regClassName	regClassDesc
0	Doesn't Matter	Doesn't Matter
10	MC	Motorcycles
20	LDV	Light Duty Vehicles
30	LDT	Light Duty Trucks
40	LHD <= 10K	Class 2b Trucks w/ 2 Axles & 4 Tires (8,500 lbs < GVWR <= 10,000 lbs)
41	LHD<=14k	Class 2b Trucks w/ 2 Axles & at least 6 Tires or Class 3 Trucks (8,500 lbs < GVWR <= 14,00(
42	LHD45	Light Heavy Duty (14K lbs < GVWR <= 19.5K lbs)
46	MHD	Medium Heavy Duty (19.5K lbs < GVWR < =33K lbs)
47	HHD	Heavy Heavy Duty (GVWR > 33K lbs)
48	Urban Bus	Urban Bus (see CFR Sec. 86.091_2)

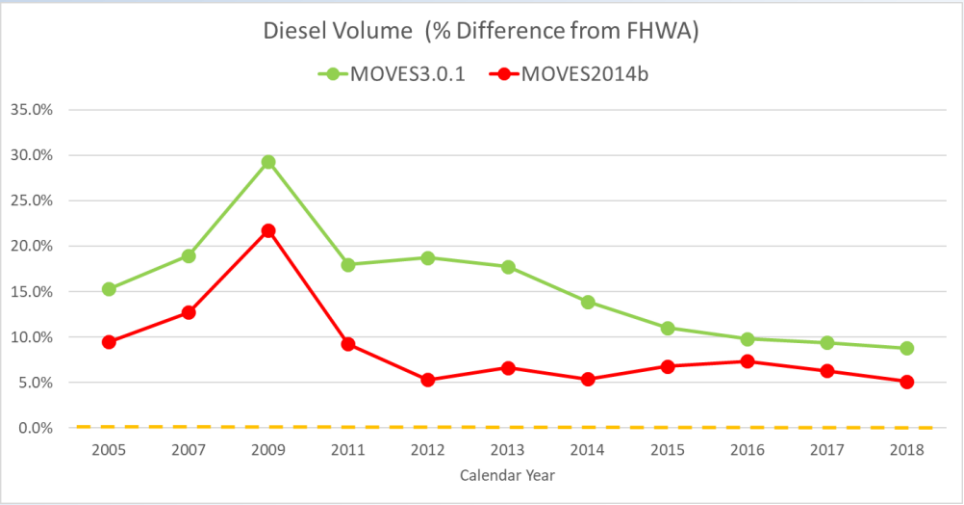
In MOVES3, no more 40's. All 2b3 are now 41's.

- Gasoline consumption volume is higher in MOVES3 compared to MOVES2014 mostly due to heavier vehicles in LD fleet

U.S. Highway Diesel Fuel Consumption

US Diesel Consumption*

Calendar Year	Diesel – Highway Use in Billion Gallons (and % Differences)				
	FHWA	MOVES3.0.1		MOVES2014b	
2005	39.1	45.1	15.3%	42.8	9.5%
2007	40.7	48.4	19.0%	45.9	12.7%
2009	35.3	45.6	29.3%	43.0	21.8%
2011	37.1	43.8	18.0%	40.5	9.2%
2012	37.4	44.4	18.7%	39.4	5.3%
2013	38.4	45.2	17.7%	41.0	6.6%
2014	39.7	45.2	13.9%	41.8	5.4%
2015	40.5	45.0	11.0%	43.2	6.8%
2016	41.6	45.7	9.8%	44.7	7.3%
2017	42.7	46.7	9.4%	45.4	6.3%
2018	43.5	47.3	8.8%	45.7	5.1%

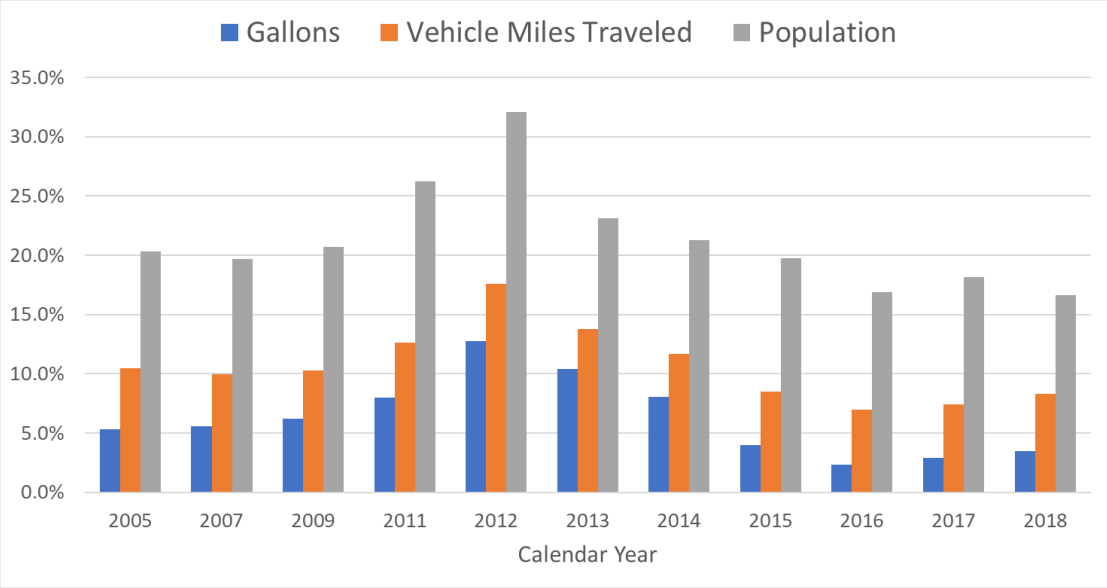


- MOVES3.0.1 & MOVES2014 are higher than FHWA for all the years
- But comparisons improve for recent years

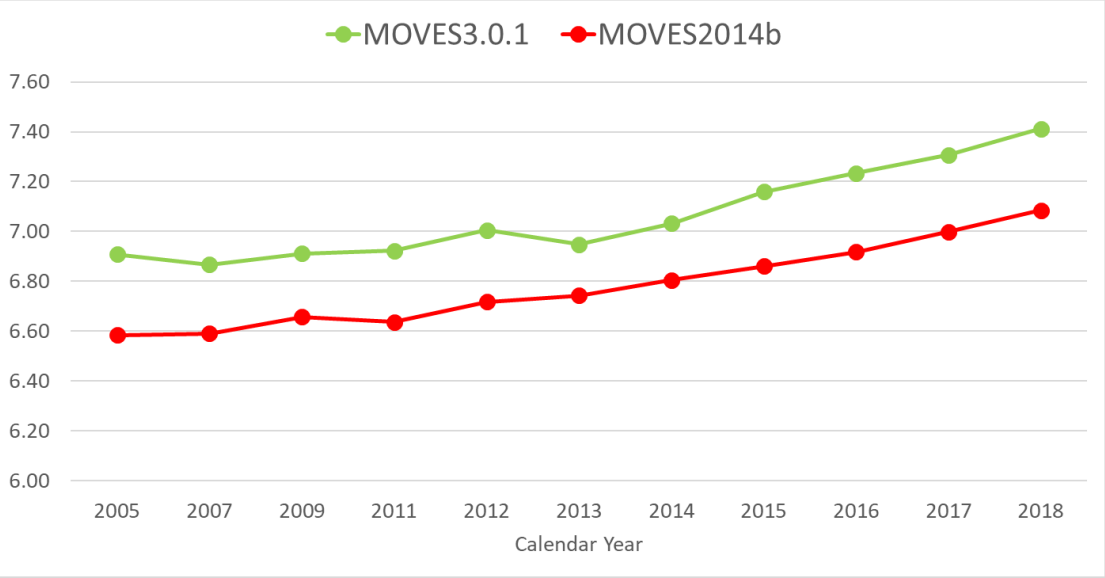
*FHWA data excludes "Public vehicles";
MOVES values exclude Transit Bus (42), School Bus (43), Refuse Truck (51) source types

US Diesel:
Impacts of MOVES Update

Summary of % Changes (MOVES3.0.1 – MOVES2014b)



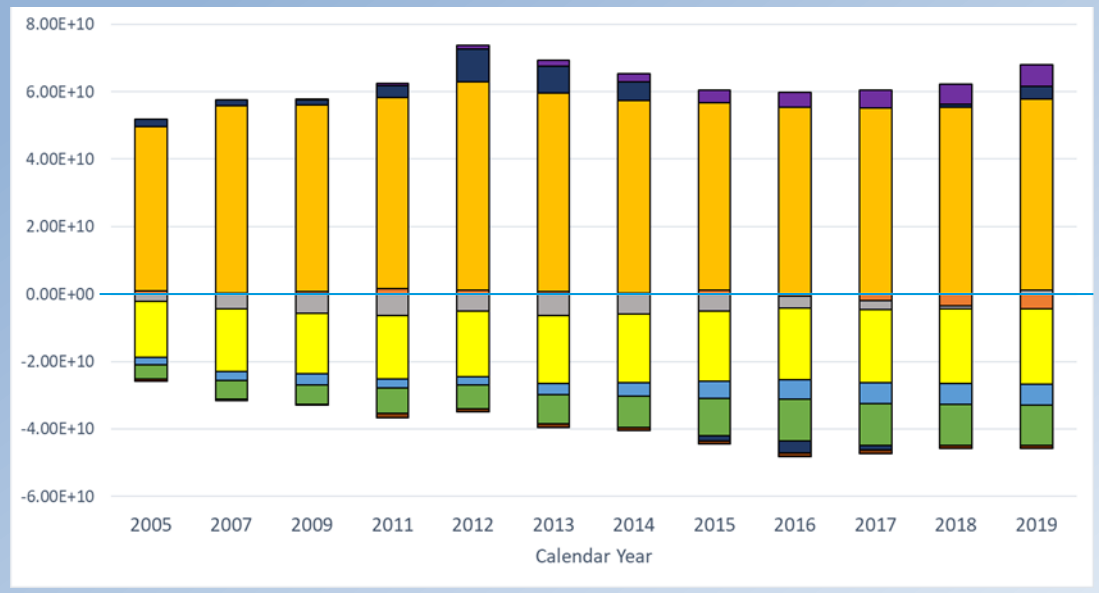
Miles Per Gallon (MPG) Comparison

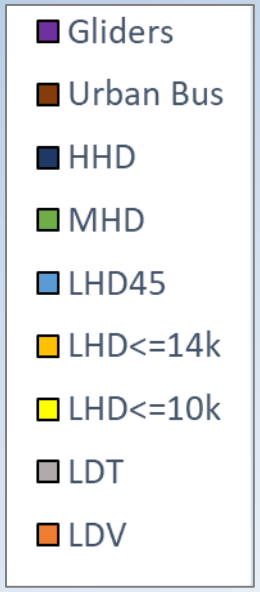


- In MOVES3, compared to MOVES2014b
  - Percent increase in diesel fuel consumption is less than VMT and VPOP changes
  - That is, average diesel fleet MPG becomes higher
  - Due to fleet changes and changes in energy rates

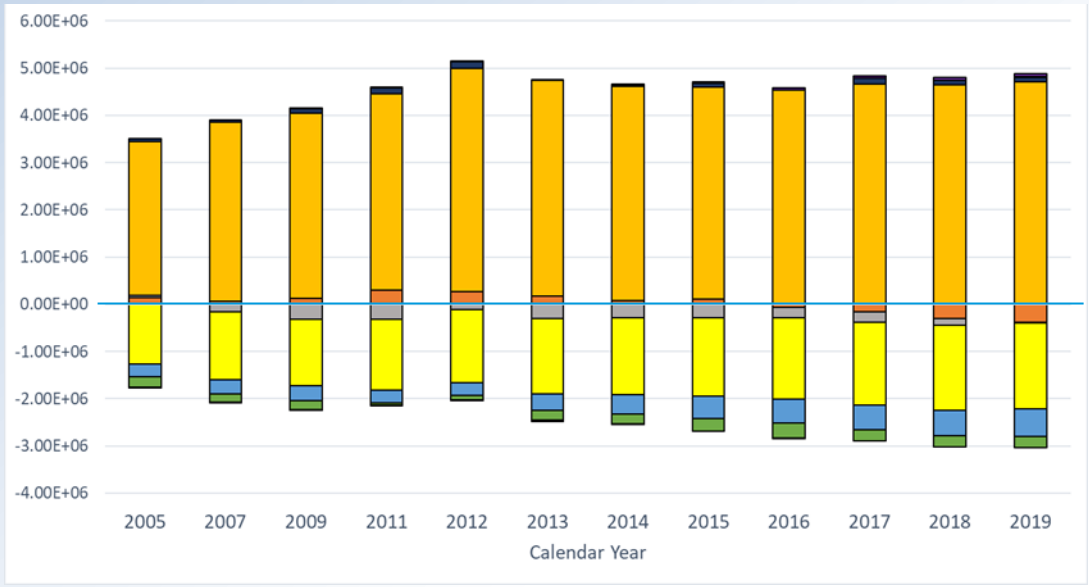
US Diesel:
Impacts of MOVES Update

VMT differences (MOVES3.0.1 – MOVES2014b) **by Regulatory Class**





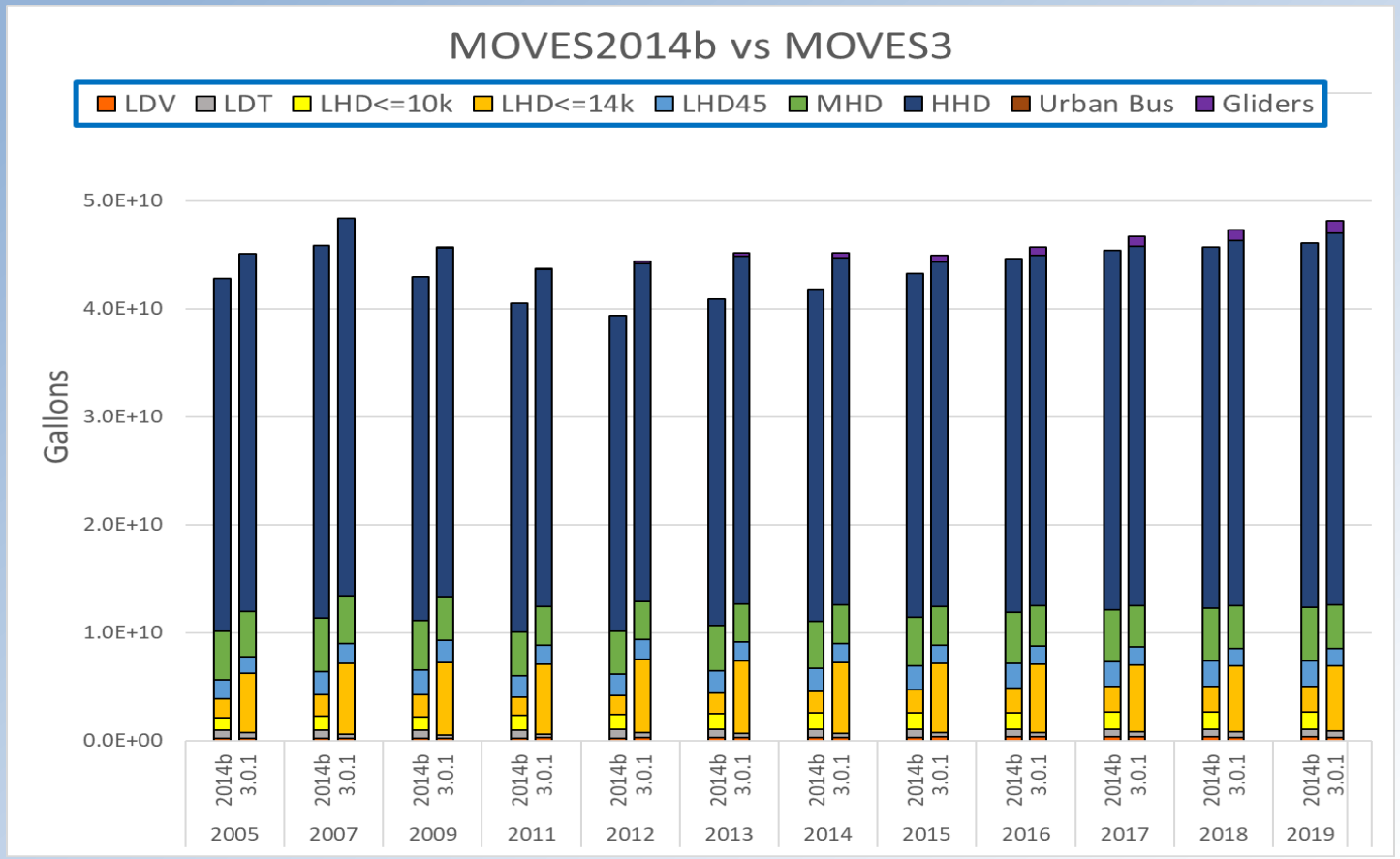
VPOP differences (MOVES3.0.1 – MOVES2014b) **by Regulatory Class**



- Compared to MOVES2014b, MOVES3.0.1 has different diesel fleet characteristics:
  - Total national VMT and VPOP are increased significantly in MOVES3.0.1
  - More “2b3” and HHD class trucks
  - “Gliders” are new in MOVES3.0.1

US Diesel:
Impacts of MOVES Update

Diesel Volume Comparison by Regulatory Class



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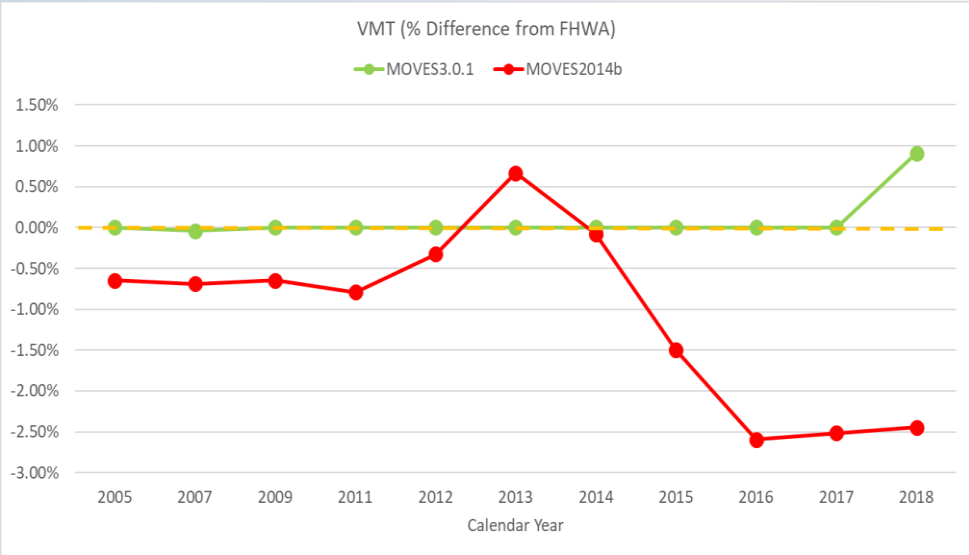
In MOVES3, no more 40's. All 2b3 are now 41's.

- Diesel volume increase in MOVES3 is driven by increases in VMT and VPOP, but the magnitude of the increase is offset by the updates to HD energy rates for MY2010+ vehicles
- Regulatory Class LHD 2b3 (41) contributes most to the diesel volume increase

VMT Comparison

US Aggregated VMT

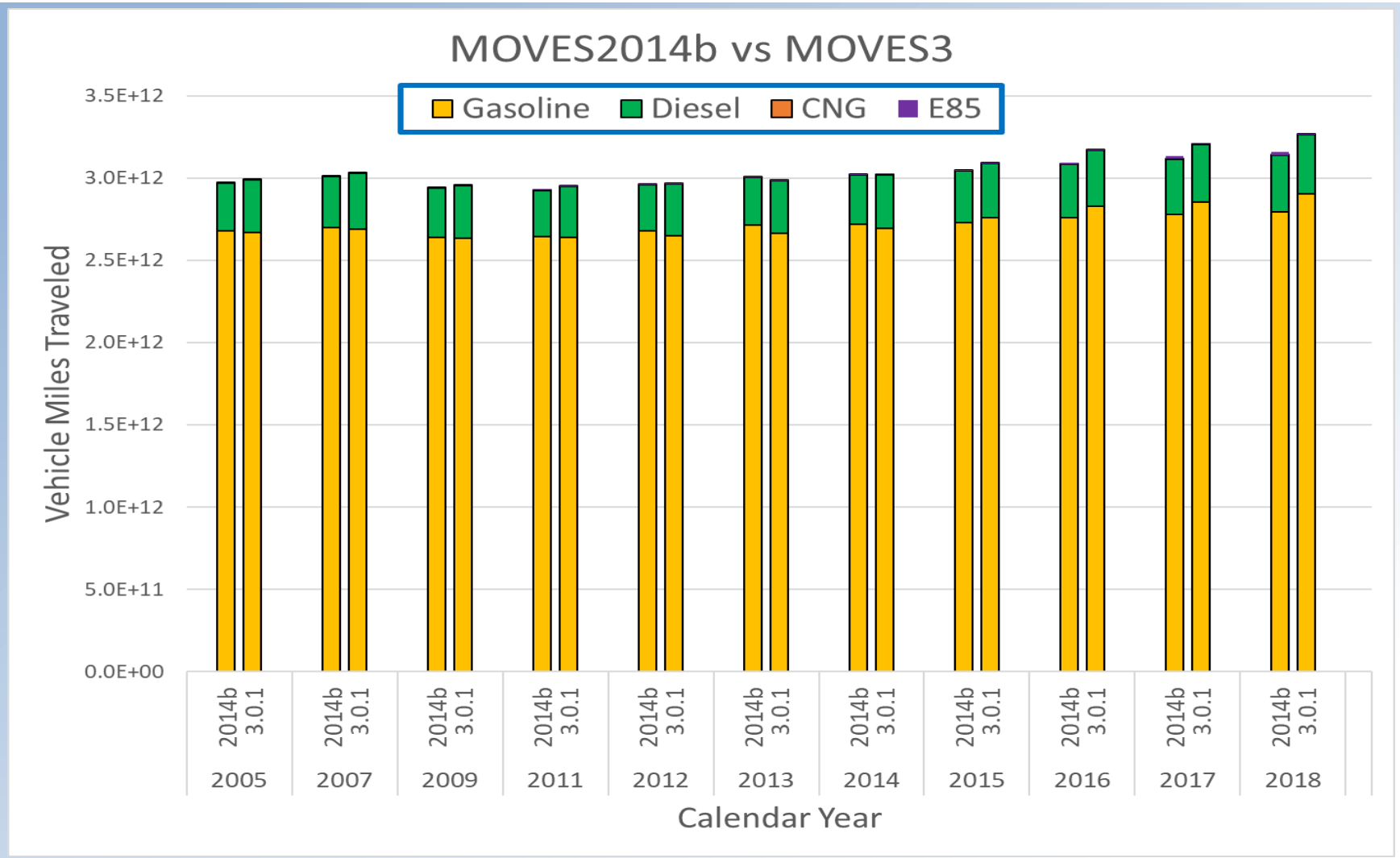
Calendar Year	VMT in Million Miles (and % Differences from FHWA)				
	FHWA^	MOVES3.0.1		MOVES2014b	
2005	2,989,430	2,989,431	0.00%	2,970,178	-0.64%
2007	3,032,399	3,031,125	-0.04%	3,011,604	-0.69%
2009	2,956,764	2,956,763	0.00%	2,937,723	-0.64%
2011	2,950,401	2,950,402	0.00%	2,927,158	-0.79%
2012	2,969,433	2,969,433	0.00%	2,959,808*	-0.32%
2013	2,988,281	2,988,280	0.00%	3,008,233*	0.67%
2014	3,025,656	3,025,656	0.00%	3,023,288*	-0.08%
2015	3,095,372	3,095,373	0.00%	3,048,931*	-1.50%
2016	3,174,408	3,174,409	0.00%	3,092,109*	-2.59%
2017	3,212,347	3,212,348	0.00%	3,131,527*	-2.52%
2018	3,240,326	3,269,867*	0.91%	3,161,099*	-2.45%



^ FHWA VMT data NOT available by fuel type;
In 2011, FHWA changed their vehicle categories;
For historical years, MOVES uses FHWA VMT as input

* Based on projections

MOVES Onroad VMT by Fuel Type
Impacts of MOVES Update



- The MOVES default national **fuel type and regulatory class allocation** for each source type and model year is stored in *SampleVehiclePopulation* table.
- MOVES uses this mapping information to match source types with emission rates.
- MOVES3 allocation is based on IHS2014 (combined with other supplementary data sources such as AEO).

MOVES HD MPG Comparison with SmartWay Data

Contributors: Evan Murray, SmartWay Team

Background

- Finding data sources to compare MOVES MPG estimates to the real world is challenging
- SmartWay partners report MPG and, unlike other SmartWay measures, it is not typically calculated based on MOVES
  - Fuel consumption and VMT are both reported
  - Fleet operators have a very strong incentive to track these accurately, including for tax purposes
- In theory, SmartWay partners and MOVES should report similar MPGs

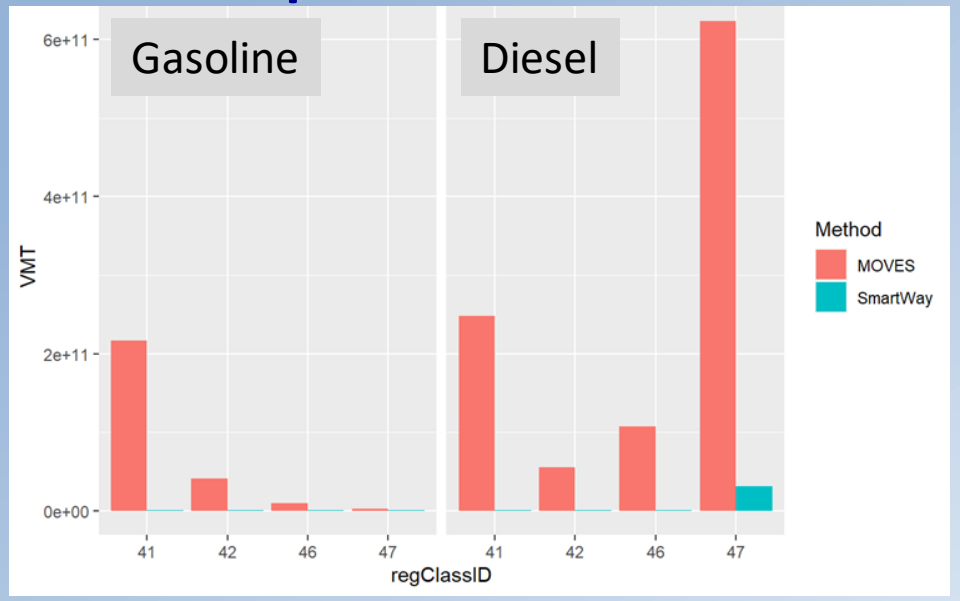
More SmartWay public data available at https://www.epa.gov/smartway/smartway-trends-indicators-and-partner-statistics-tips

Limitations

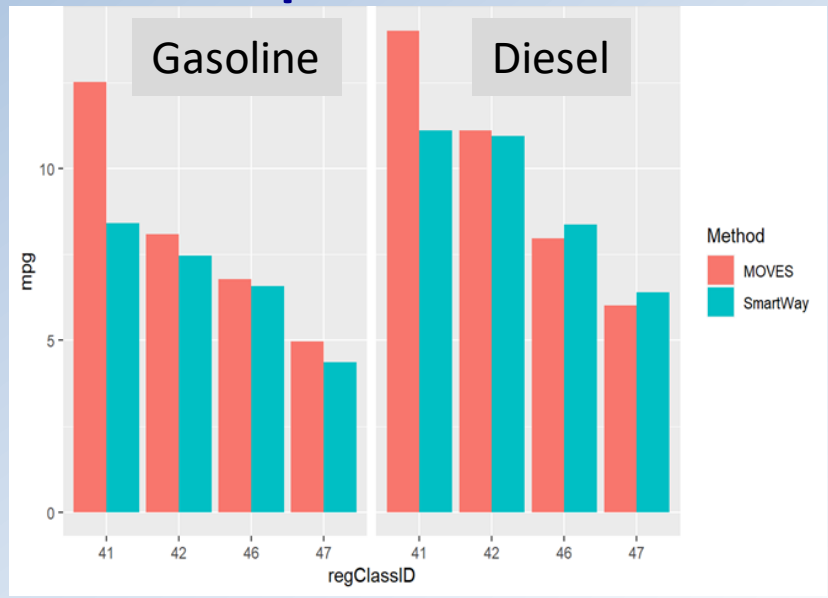
- SmartWay's sample is not random. It is likely skewed towards cleaner fleets
- For lighter classes (2b/3 in particular), SmartWay sample size is small and partners operate vehicles very differently from national averages
- Fuel efficiency varies with payload, and SmartWay's average payloads may not match those in MOVES (*sourceusetypephysics)*
- All of this said, we should still expect MOVES and SmartWay to be fairly close

Comparisons

VMT Comparison



MPG Comparison



ID	Regulatory Class
41	2b3
42	LHD
46	MHD
47	HHD

- Based on MOVES VMT estimates, SmartWay's market capture for Class 8 vehicles is about 5%
- The MPG values are comparable, with SmartWay's MPG being a bit higher than MOVES where the sample size is large
- SmartWay's 2b/3 values are likely skewed because of different operational characteristics
- The MPG values are in general agreement, suggesting MOVES operating mode distributions and heavy-duty energy consumption rates are reasonable

Conclusion

Summary

- Overall, MOVES3 fuel consumption is higher than FHWA data
  - For historical years, gasoline is within 9% and diesel is within 20% for most years
    - More uncertainties exist in diesel volume data and methodology
  - For more recent years (CY2016 and later), comparison improves
    - Within 4% and 10% for gasoline and diesel, respectively
- MOVES3 fuel consumption is also higher than MOVES2014
  - Primarily due to the updated fleet characteristics in MOVES3
    - LD gasoline fleet mix shift to heavier vehicles
    - Diesel fleet has more VMT and population, along with increase in 2b3s
- Although MPG comparison to SmartWay data does not explain the differences in fuel consumption between MOVES3 and FHWA, it serves as another data source for evaluating MOVES3 fuel consumption
- We continue to evaluate MOVES by comparing to independent data