APPENDIX A

Personal Vehicles Operational Analysis

Appendix A – Personal Vehicles Operational Analysis

This appendix consists of the (1) input parameters into the MOVES model and (2) spreadsheets that show the data and equations used in the personal vehicles operational analysis.

Sixty MOVES runs were completed to account for 10 time periods, three vehicle classes, and two analysis years. Provision of the input parameters into the MOVES model are targeted for agency review and have only been submitted electronically, which also reduces the amount of paper used for this report.

The spreadsheets showing the data and equations used in the personal vehicles operational analysis are particularly large and cannot be completely displayed on 8.5 x 11 or 11 x 17 paper. Since it is difficult to convey this information in a meaningful manner when printing these spreadsheets on numerous successive pages, these spreadsheets have been submitted in electronic format only, which also reduces the amount of paper used for this report.

APPENDIX B

Transit Operational Analysis

Appendix B – Transit Operational Analysis

This appendix consists of spreadsheets that show the data and equations used in the transit operational analysis. Due to the amount of data, these spreadsheets are particularly large and cannot be completely displayed on 8.5 x 11 or 11 x 17 paper. Since it is difficult to convey the information in a meaningful manner when printing these spreadsheets on numerous successive pages, this appendix has been submitted in electronic format only, which also reduces the amount of paper used for this report.

APPENDIX C

Methodology Comparison and Validation

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TECHNICAL MEMORANDUM

Date:	March 18, 2010
To:	Jeff Heilman
From:	Peter Chen
Subject:	Greenhouse Gas Analysis - DEIS Methodology Validation
cc:	
Project Number:	273-3012-004
Project Name:	Columbia River Crossing

INTRODUCTION

At the time when the Columbia River Crossing (CRC) Draft Environmental Impact Statement (DEIS) was prepared there were no methodologies accepted industry-wide that estimated operational energy use and greenhouse gas (GHG) emissions associated with transportation projects. The methodology used in the DEIS was based on a well-established equation that related distances traveled and fuel economy to estimate the amount of fuel consumed. The DEIS methodology was novel in the sense of how it integrated carbon dioxide (CO_2) emission factors for different energy sources (e.g. gasoline, diesel, electricity etc.), utilized traffic simulation data, and accounted for the operational speeds of the project by using different fuel economies according to vehicle class and over a speed distribution.

Since that time, the Environmental Protection Agency (EPA) released the Mobile Vehicle Emission Simulator (MOVES) model. The MOVES model is intended to replace EPA's previous air quality model, MOBILE6, but also estimates operational carbon dioxide equivalent (CO_2e) emissions, which are equated to GHG emissions. Based on stakeholder input and project staff recommendations, the CRC project decided to use the MOVES model to for the operational energy and GHG emissions analyses in the Final Environmental Impact Statement (FEIS).

Since no other methodologies were available at the time when the DEIS was prepared to gauge the accuracy of the estimates, the project team deemed it desirable to confirm the validity of the methodology and conclusions presented in the DEIS.

PURPOSE

The primary purpose of this analysis is to determine if the methodology used in the DEIS produces GHG emission estimates similar to the MOVES model, thereby validating the analysis presented in the DEIS.

The secondary purpose of this effort is to examine the input assumptions made in the DEIS and determine if those values were reasonable, thereby validating the conclusions presented in the DEIS.

APPROACH

To validate the methodology used in the DEIS and its conclusions, the GHG estimates produced by the MOVES model for the FEIS were compared to estimates resulting from the DEIS methodology.

It is important to distinguish the differences between the terms "methodology" and "input assumptions." For the purposes of this report, "methodology" refers to the collection of parameters and their relationships used to derive the estimates, such as traffic volumes, fleet mixes, distance traveled, and operating speeds. The term "input assumptions," in this report, refers to the specific values of parameters. To illustrate the differences between these terms, an example of two different mathematical methodologies is presented below.

Method 1:	**Method 2:**
2 (5 + 3) = x	2 (5 + 3) = x
2 (8) = x	(2 * 5) + (2 * 3) = x
16 = x	(10) + (6) = x
	16 = x

In the example above, the specific sequence of multiplication and addition is the methodology and the numbers are the input assumptions. Both methodologies are valid means to the same answer, so long as the input assumptions are consistent.

Methodology Validation

As defined above, "methodology" refers to the collection of parameters and the relationships between those parameters. Table 1 shows a non-exhaustive list of the different parameters used in the DEIS and MOVES methodologies, which illustrate the similarities and differences.

The methodology used in the DEIS is more simple compared to the MOVES model; it aggregates some parameters (e.g., vehicle classes) and does not account for other parameters (e.g., vehicle age distribution, road type, and drive cycles).

While the DEIS and MOVES methodologies are somewhat different, it was hypothesized that they both produce similar GHG emission estimates. It was also hypothesized that differences in the GHG emission estimates are primarily due to different input assumptions, not the methodology. The two primary input assumptions assumed to have the most substantial effects are the existing fuel consumption rates (FCRs) and the future projections.

To test these hypotheses and determine the magnitude of effect of the two primary input assumptions, the following three scenarios were identified and compared to GHG emission estimates using the MOVES model with MOVES 2005 FCRs and MOVES 2030 projections:

- **Scenario 1 – DEIS 2005 FCRs and DEIS 2030 Projections.** The two primary input assumptions, existing and future fuel economies, remain as they were in the DEIS. This scenario identifies the cumulative effect of both of these input assumptions.
- **Scenario 2 – DEIS 2005 FCRs and MOVES 2030 Projections.** Under this scenario, the existing FCRs remain as they were in the DEIS, but the projected fuel economies are made consistent with those identified by MOVES. By using the same projections (i.e., rates of increase/decrease between existing and future fuel economies according to MOVES), this scenario tests the effect of the existing FCRs.
- **Scenario 3 – MOVES 2005 FCRs and DEIS 2030 Projections.** Under this scenario, the existing FCRs were changed to be consistent with MOVES, but the projected fuel economies are based on the DEIS data. By using the same existing FCRs (according to MOVES), this scenario tests the effect of the future projections.

Table 1. Methodology Comparison

	Methodology	
Parameter	**DEIS**	**MOVES**
Volume - Combination Long Haul Truck	200 vph of "Heavy Truck"	100 vph
Volume - Combination Short Haul Truck		25 vph
Volume - Single Unit Long Haul Truck		75 vph
Volume - Motor Home	NA	1 vph
Volume - Motorcycle	NA	3 vph
Volume - Passenger Car	9,750 vph of "Car"	7,300 vph
Volume - Passenger Truck		2,450 vph
Volume - Light Commercial Truck	150 vph of "Medium Truck"	100 vph
Volume - Refuse Truck		2 vph
Volume - Single Unit Short Haul Truck		48 vph
Volume - School Bus	35 vph of "Bus"	2 vph
Volume - Intercity Bus		15 vph
Volume - Transit Bus		18 vph
Road Type	NA	Un/Restricted
Month(s) of Year	NA	June
Weekdays/Weekends	NA	Weekdays
Hour(s) of Day	6:00 - 10:00 AM	6:00 - 10:00 AM
Vehicle Age Distribution	NA	1 Yr old (2%), 2 Yrs old (4%)
Distance Travelled	10 miles	10 miles
Average Speed	50 mph	50 mph
Drive Cycle	NA	Yes
Temperature	NA	55 F
Humidity	NA	75%
Carbon Dioxide Equivalency Factor	100/95	NA

Input Assumptions Validation

The EPA routinely tests the fuel economy of new cars for “city” and “highway” conditions, which typically consist of an average operating speed of 21.2 mph and 48.3 mph over distances of 11.04 and 10.26 miles, respectively (EPA 2009). These tests provide the “EPA rated” fuel efficiencies found at car dealerships.

The Energy Information Administration (EIA) is a branch of the U.S. Department of Energy that gathers information and data from multiple resources, such as the EPA, to provide statistics and forecasts. The EIA produces the Annual Energy Outlook that revisits past data, market trends, technological advances, and policy changes to refine forecasts on an annual basis. These forecasts often serve as the best available data.

To validate the input assumptions presented in the DEIS, the existing and future fuel economies were compared to EIA Annual Energy Outlook data.

ANALYSIS

Methodology Results

The initial sensitivity analysis, Scenario 1, compared the DEIS and MOVES GHG emission estimates that differed by both methodology (DEIS and MOVES) and input assumptions (existing and projected fuel economies). The analysis was conducted for all existing and future alternatives for redundancy (i.e. higher confidence) purposes and is summarized in Table 2.

Table 2. Scenario 1 GHG Emission Comparison

	DEIS Methodology		MOVES Methodology		
Alternative	MT CO2e	Rank (High to Low)	MT CO2e	Rank (High to Low)	% Difference
Existing	229.7	5	273.5	5	19.1%
No Build	289.6	2	389.4	2	34.5%
No Build - Bridge Lift	295.6	1	396.8	1	34.2%
LPACO	277.7	3	371.6	3	33.8%
RP2	274.9	4	367.9	4	33.9%

Although the relative differences ("rank") between alternatives were consistent between the DEIS and MOVES estimates, which are often the focus for decision-making purposes, the absolute differences were more substantial with the MOVES estimates being approximately 34 percent higher.

Due to this magnitude of difference, another analysis, Scenario 2, was conducted that substituted the DEIS future projection rates for fuel economy with the MOVES projections (i.e., projections were held constant and existing fuel economies were the variable parameter). These emission estimates are summarized in Table 3.

Table 3. Scenario 2 GHG Emission Comparison

	DEIS Methodology		MOVES Methodology		
Alternative	MT CO2e	Rank (High to Low)	MT CO2e	Rank (High to Low)	% Difference
Existing	229.7	5	273.5	5	19.1%
No Build	317.7	2	389.4	2	22.6%
No Build - Bridge Lift	324.1	1	396.8	1	22.4%
LPACO	306.7	3	371.6	3	21.1%
RP2	303.5	4	367.9	4	21.2%

Table 3 shows that the alternative ranking remained consistent and the absolute differences between DEIS and MOVES estimates was reduced to approximately 22 percent. This indicates that the different input assumptions related to future fuel economies affects the absolute difference by roughly 12 percent (34 percent difference under Scenario 1 compared to 22 percent difference under Scenario 2; 12 percent effect).

A third scenario examined the effects of the existing fuel economy assumptions by holding the existing fuel economies constant (i.e., the existing fuel economies for the DEIS methodology were made equal the MOVES fuel economies) and letting the projections be the variable parameter. These results are shown in Table 4.

Table 4. Scenario 3 GHG Emission Comparison

	DEIS Methodology		MOVES Methodology		
Alternative	**MT CO2e**	**Rank (High to Low)**	**MT CO2e**	**Rank (High to Low)**	**% Difference**
Existing	278.5	5	273.5	5	-1.8%
No Build	354.4	2	389.4	2	9.9%
No Build - Bridge Lift	361.2	1	396.8	1	9.8%
LPACO	335.9	3	371.6	3	10.6%
RP2	332.8	4	367.9	4	10.6%

By changing the existing fuel economy input assumption in the DEIS methodology to equal the MOVES existing fuel economies, the ranking order remained consistent and the absolute difference between the DEIS and MOVES estimates was reduced to approximately 10 percent. By comparing these results to the results for Scenario 1, the existing fuel economy assumptions used in the DEIS has an affect of approximately 24 percent (34 percent difference under Scenario 1 compared to 10 percent difference under Scenario 3; 24 percent effect).

As described above, these three sensitivity analyses were conducted for all future alternatives for increased redundancy. However, focusing on the existing conditions in Table 4 also removes the effects of differing input assumptions related to future projections. Since the existing conditions estimates under Scenario 3 vary only by methodology (i.e., the existing fuel economy input assumptions were standardized), these estimates provide the best "apples-to-apples" comparison of the two methodologies. A difference of 1.8 percent between the two methodologies indicates that the DEIS methodology produces very similar estimates compared to the MOVES model.

Based on these sensitivity analyses, we can identify several conclusions:

- The existing fuel economy input assumption has the greatest effect compared to the future projections input assumption (24 percent effect compared to 12 percent effect, respectively).
- When input assumptions are the same, the DEIS methodology provides CO2e emission estimates that are approximately 1.8 percent within the MOVES estimates; i.e., the additional parameters included in the MOVES model (see Table 1) only affect emission estimates by a nominal amount.
- The input assumptions included in the DEIS and MOVES methodologies result in larger GHG emission estimates and are the primary cause for differences, not the methodology itself.
- Given that the relative difference ("ranking") between alternatives always remained consistent between the DEIS and MOVES estimates for all sensitivity tests, the methodology used in the DEIS and the conclusions drawn from the analyses are valid for evaluating alternatives.

Input Assumptions Results

The three sensitivity tests analyzed above indicate that the primary differences between the DEIS and MOVES GHG emission estimates are not due to the methodologies, rather the input assumptions used in those methodologies.

The DEIS input assumptions for existing and future fuel economies were based on data provided in the ODOT Energy Manual (ODOT 2006) and EIA's Annual Energy Outlook 2007 (EIA 2007). Figures 1 through 3 illustrate the differences between the DEIS and MOVES input assumption for existing fuel economies per vehicle class. These figures also provide a comparison to EIA data; however this data is limited to "highway" conditions at operating speeds of approximately 48.3 mph.

Figure 1. 2005 Car Fuel Economies

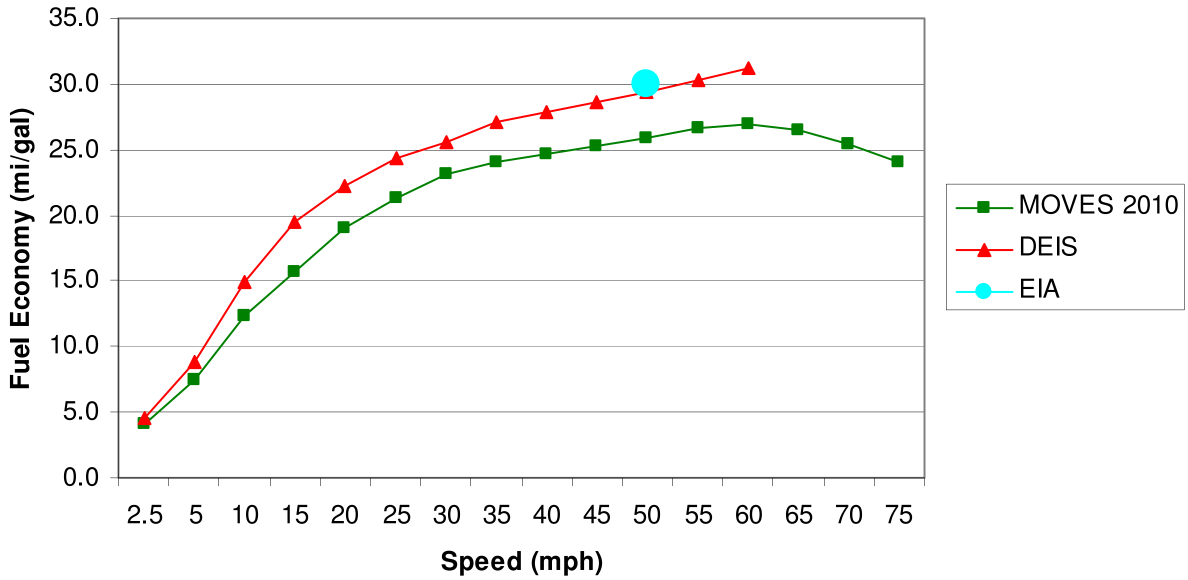


Figure 2. 2005 Medium Truck Fuel Economies

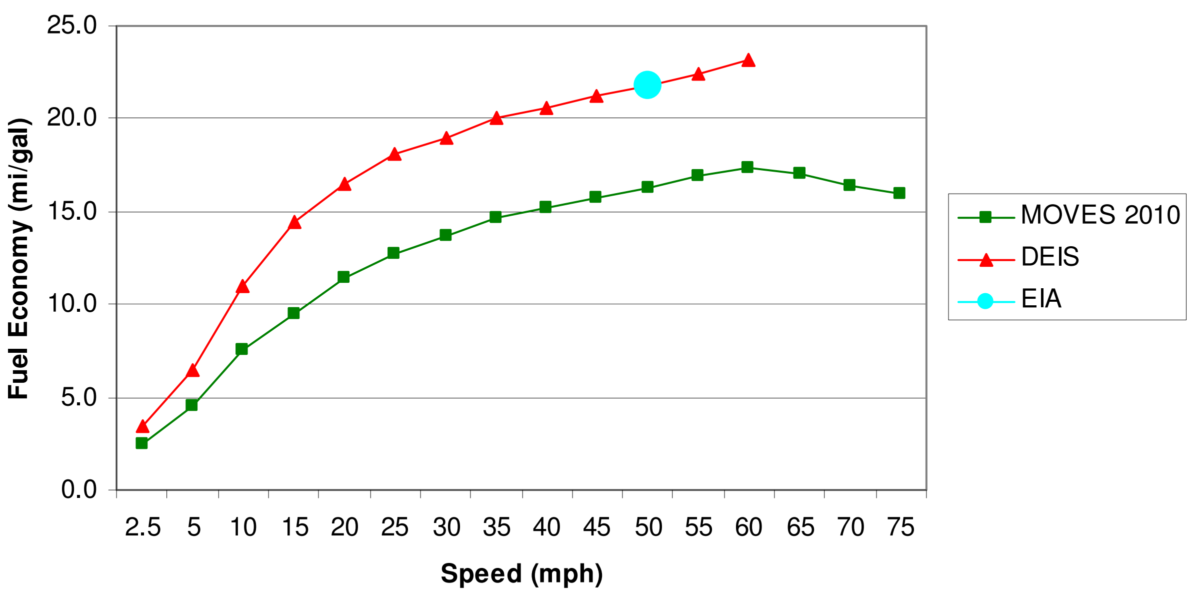
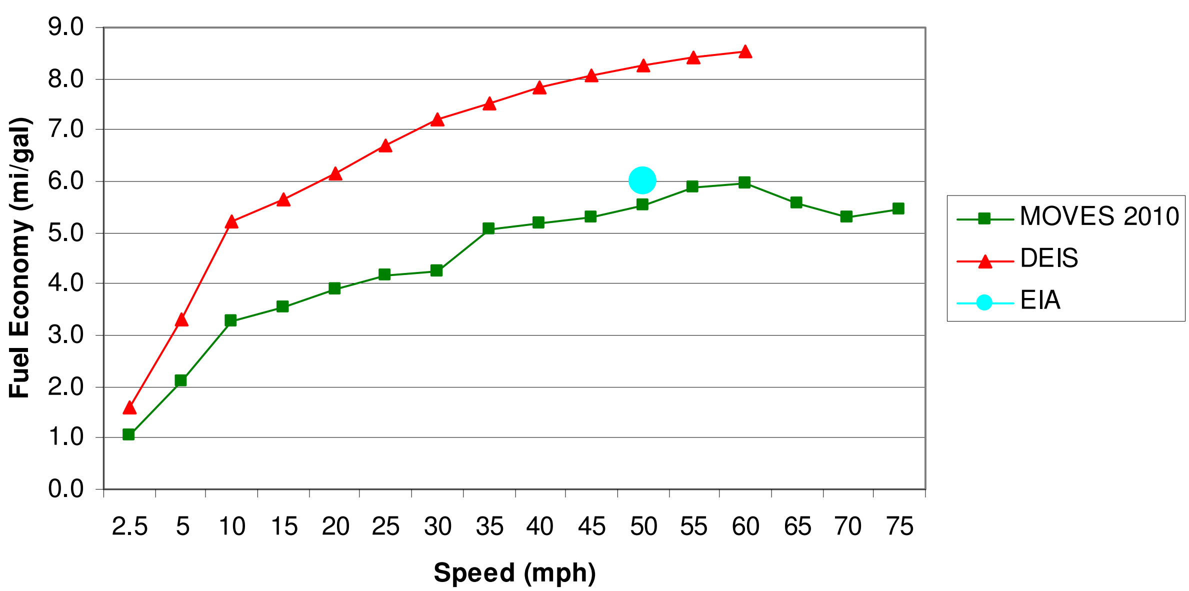


Figure 3. 2005 Heavy Truck Fuel Economies



Figures 1 through 3 indicate:

- Both DEIS and MOVES input assumptions for existing fuel economies over a speed distribution are fairly similar.
- The DEIS existing fuel economies are consistently higher (more fuel efficient) compared to MOVES fuel economies for all vehicle classes.
- For two of the three vehicle classes (cars and medium trucks), the DEIS existing fuel economies are more similar to EIA data compared to the MOVES fuel economies.

Figures 4 through 6 compare the future 2030 fuel economies included in the DEIS and MOVES methodologies as well as EIA forecasts.

Figure 4. 2030 Car Fuel Economies

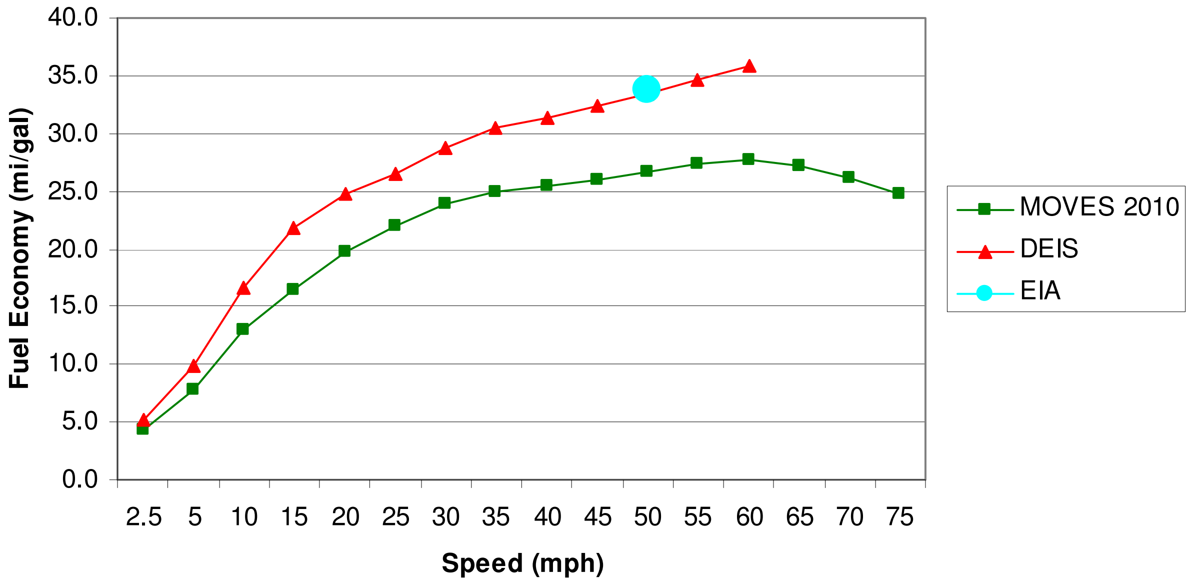
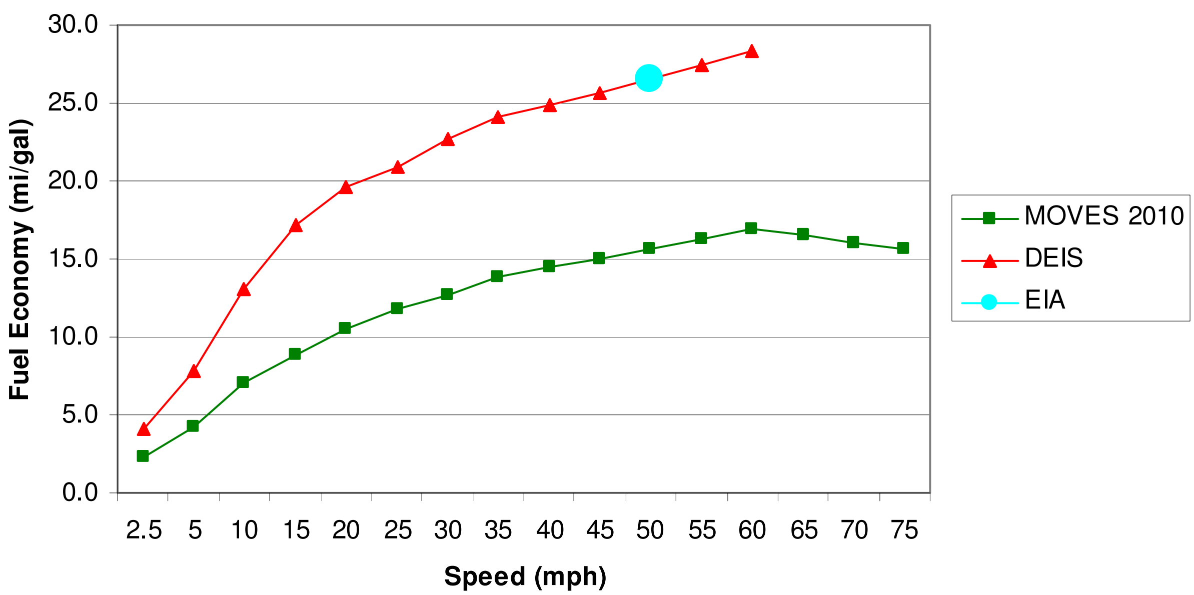
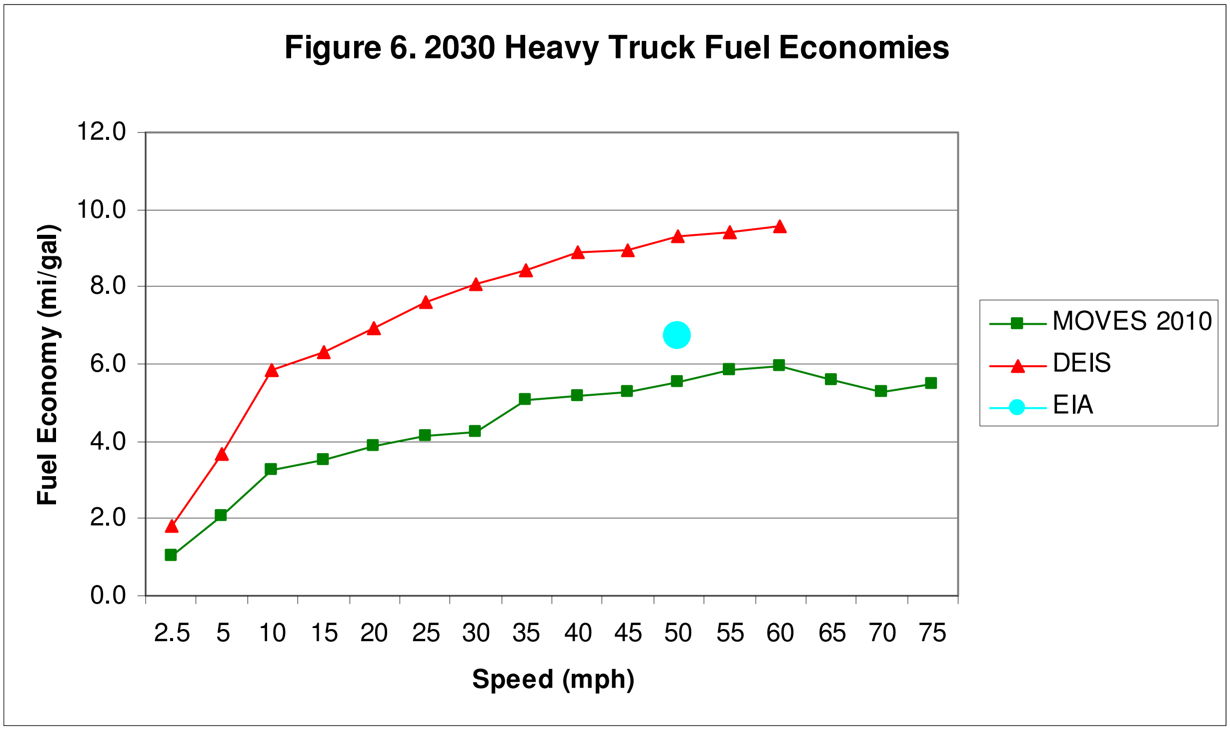


Figure 5. 2030 Medium Truck Fuel Economies





Figures 4 through 6 indicate:

- Both DEIS and MOVES input assumptions for future fuel economies over a speed distribution are fairly similar.
- The DEIS future fuel economies are consistently higher (more fuel efficient) compared to MOVES fuel economies for all vehicle classes.
- For two of the three vehicle classes (cars and medium trucks), the DEIS future fuel economies are more similar to EIA data compared to the MOVES fuel economies.

These differences in future 2030 fuel economies are due to two factors: existing fuel economies and projections (i.e., rate of increase in fuel efficiency between 2005 and 2030). Future fuel economies were compared to existing fuel economies for both the DEIS and MOVES input assumptions to identify projection rates and are shown in Figures 7 through 9, which also provide a comparison to EIA projections.

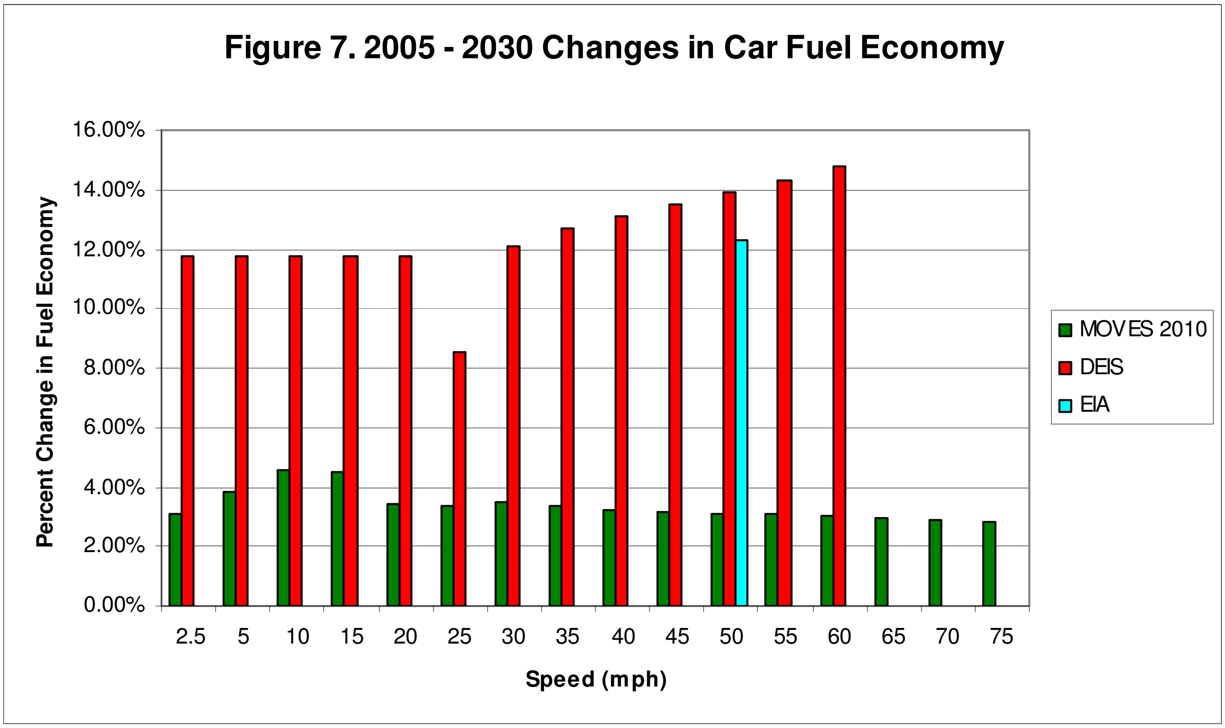


Figure 7. 2005 - 2030 Changes in Car Fuel Economy
16.00%
14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
2.00%
0.00%
Percent Change in Fuel Economy
2.5 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
Speed (mph)
MOVES 2010
DEIS
EIA

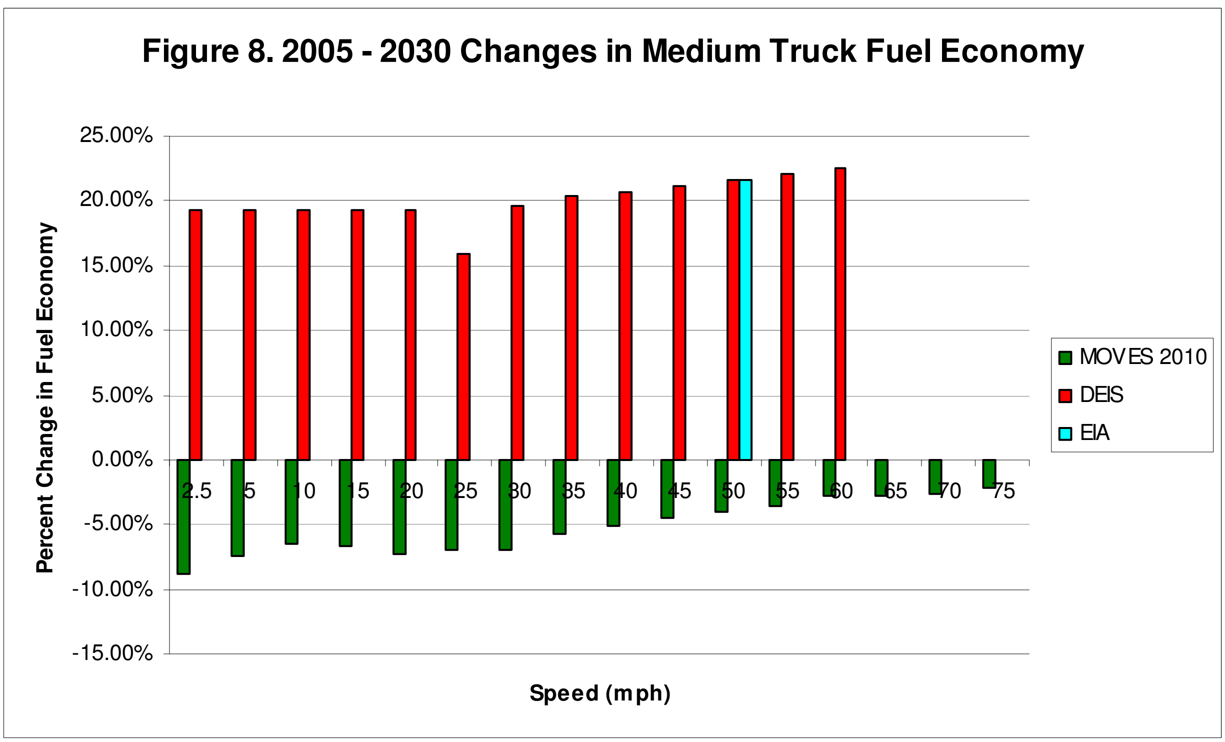
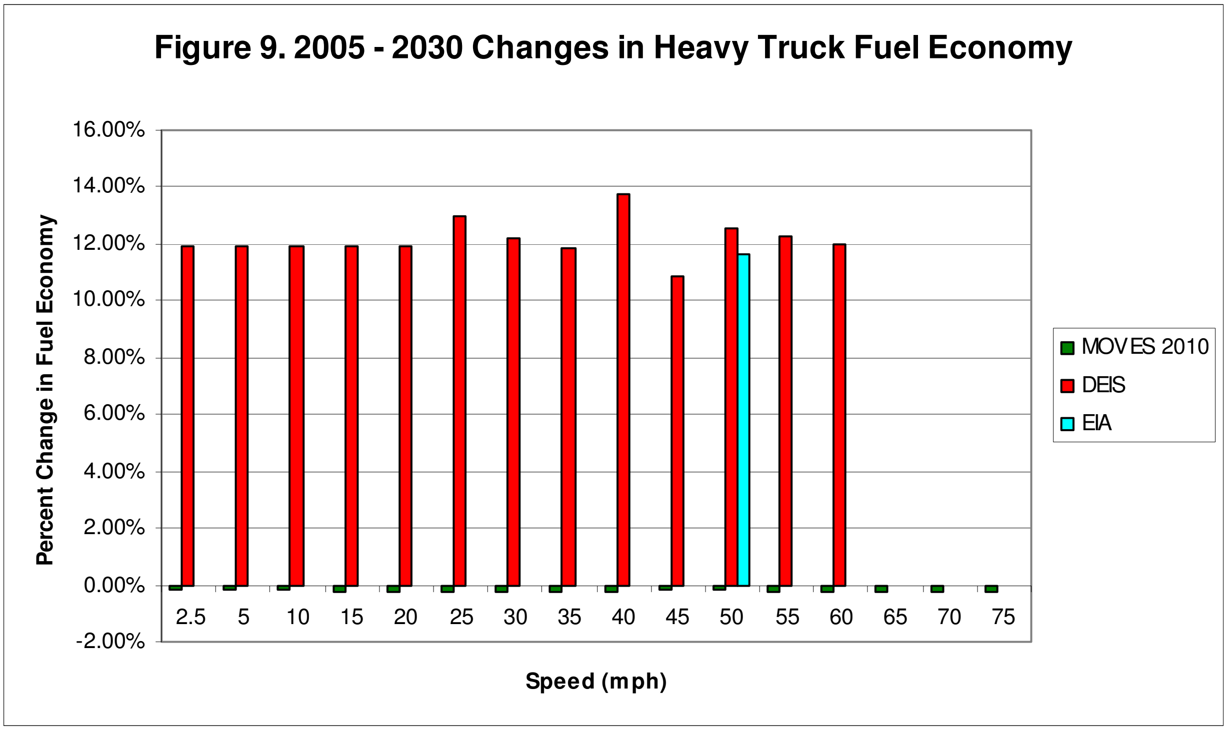


Figure 8. 2005 - 2030 Changes in Medium Truck Fuel Economy
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
-5.00%
-10.00%
-15.00%
Percent Change in Fuel Economy
2.5 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
Speed (mph)
MOVES 2010
DEIS
EIA



Figures 7 through 9 show several different trends, including:

- The DEIS projections for cars (9 to 15 percent) are much higher compared to MOVES (3 to 5 percent); EIA projections are most similar to the DEIS projections (12 percent).
- The DEIS projections for medium trucks range between 16 and 23 percent and the EIA projections are also comparable at 22 percent. The MOVES projections are substantially different and suggest that future fuel medium trucks will be less fuel efficient compared to existing medium truck by approximately 2 to 9 percent.
- The DEIS (11 to 14 percent) and EIA projections (12 percent) for heavy trucks are fairly similar, whereas the MOVES projections are essentially flat.

Although similarities and differences between the DEIS, MOVES, and EIA fuel economies cannot be absolutely and empirically identified, background knowledge on these methodologies provides insight and sound deductions on the likely responsible variables: definitions of vehicle classes, technology improvements, and vehicle age distribution.

Vehicle Classes

To be consistent with the Metro travel demand model, the DEIS methodology utilized a vehicle classification system consisting of cars, medium trucks, and heavy trucks. Within this system, the term "car" refers to common passenger vehicles, such as sedans, and excludes other vehicles, such as motorcycles and motorhomes. Conversely, the vehicle types included in MOVES are more specific and similar to FHWA's 13-vehicle classification system; motorcycles and motorhomes, for example, are considered separate vehicle classes. To be consistent with the three-vehicle classification system of Metro's regional travel demand model, the vehicle types in MOVES were aggregated to produce three emission rates, one for each vehicle class in Metro's regional demand model. While the proportion of motor homes is small, their effects do play a role on why the aggregated MOVES fuel economies for "cars" would tend to be lower compared to DEIS estimates.

The definition of "medium trucks" has a similar effect. A common definition is based largely on "looks" and how that vehicle operates in traffic with respect to accelerating, decelerating, and following distances. The MOVES criteria that distinguish medium and heavy trucks, which follow the more strict FHWA classification system, are based on the number of units, axles, and weight. As a result, some trucks that would be commonly considered by the general public as a "heavy truck" is actually classified as a "medium truck," which then reduces the average fuel economy for the medium truck vehicle class. Furthermore, MOVES allows each model year to contain different mixes of vehicle weights and fuel types. It may be that the 2030 fleet for medium trucks is heavier and/or a greater proportion uses diesel compared to the 2005 fleet, therefore resulting in higher emissions on average for the "medium truck" vehicle class (Brzezinski 2010).

Technology Improvements

MOVES also does not speculate on improvements to vehicle fuel efficiency in future model years, unless the improvements are required by regulations already in place. For example, if a pickup truck of a specific size and weight achieves 20 mpg in 2005, a truck of similar size and weight in 2030 will also get 20 mpg, unless there is some regulatory justification for the fuel economy to improve (Brzezinski 2010). The 2007 Corporate Average Fuel Economies (CAFE) standards are included in MOVES2010.

Vehicle Age Distribution

Likely the largest contributor to the differences between DEIS and MOVES assumptions for fuel economies is the vehicle age distribution, which refers to the proportion of vehicles in use that are one year old, two years old, etc. As shown above in Table 1, the DEIS methodology does not include this parameter, whereas MOVES does. Since the DEIS fuel economies were based on data provided by ODOT and EIA, these fuel economies do not include older vehicles that were originally less fuel efficient and are even less fuel efficient over time. For example, the DEIS projections assume that cars (i.e., new cars) operating at 60 mph will achieve a fuel economy of 35.9 mpg and this fuel economy is applied to all car VMT in 2030. This new car fuel efficiency may in fact be consistent with the MOVES projections; however, since MOVES accounts for vehicle age distribution, the proportion of new cars that achieve this fuel economy may be small and the majority of cars have a much lower fuel economy, thus lowering the total 2030 average.

CONCLUSIONS

Three sensitivity analyses were completed to compare the GHG emission estimates from the DEIS and MOVES methodologies. For all three tests, the relative differences ("rank") between alternatives remained consistent, which is often the focus for decision-making purposes. When the input assumptions (i.e., existing and future fuel economies) were made consistent between both methodologies, the resulting GHG emission estimates were within 1.8 percent of each other. The 1.8 percent difference represents the effects of the additional parameters that the MOVES model takes into account. Based on this small difference and since the relative differences always remained consistent between the DEIS and MOVES emission estimates, it was concluded that both methodologies produce very similar emission estimates and that the approach taken in the DEIS was valid.

The existing and future fuel economies assumed in the DEIS and MOVES methodologies exhibit a very similar trend over a speed distribution. Although the MOVES projections take additional factors into account that the DEIS input assumptions do not, such as vehicle age distribution, the DEIS fuel economies are highly consistent with EIA data and generally consistent with MOVES; therefore, the DEIS input assumptions were deemed valid.

Based on the validity of the DEIS methodology and input assumptions, conclusions presented in the DEIS also remain valid.

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ODOT. 2006. *Draft Energy Manual*. Oregon Department of Transportation.

APPENDIX D

Construction Analysis

Appendix D – Construction Analysis

This appendix consists of spreadsheets that show the data and equations used in the construction analysis. Due to the amount of data, these spreadsheets are particularly large and cannot be completely displayed on 8.5 x 11 or 11 x 17 paper. Since it is difficult to convey the information in a meaningful manner when printing these spreadsheets on numerous successive pages, this appendix has been submitted in electronic format only, which also reduces the amount of paper used for this report.