Appendix F – GPRA07 Vehicle Technologies Program Documentation

1. Introduction

The target markets for the Office of FreedomCAR and Vehicle Technologies (FCVT) program include light vehicles (cars and light trucks) and heavy vehicles (trucks more than 10,000 pounds Gross Vehicle Weight). Each will be discussed separately below.

1.1 Target Market: Alternate Technology Light Vehicle (ATV) Market

The alternate technology light vehicles (ATVs) included in the FCVT program are gasoline hybrid vehicles, diesel hybrid vehicles, advanced diesel, and advanced gasoline vehicles. The market for these technologies includes all cars and light trucks sold for both personal and business use. Today, the size of this market is approximately 17 million vehicle sales per year. Total car and light truck stock is about 220 million vehicles. EIA projects both sales and stock to grow to more than 20 million and 300 million, respectively, by 2025. Additional growth is expected post-2025, as explained in Chapter 2. The vehicle miles of travel are projected to grow from 3.28 trillion in 2020 to 5.63 trillion in 2050.

1.2 Key Factors in Shaping the Market Adoption of ATVs

Key factors associated with the adoption of new vehicle technologies include how the new vehicle technologies compare with the baseline vehicle technologies in terms of the following vehicle attributes:

- Vehicle Price
- Fuel Economy
- Range
- Maintenance Cost
- Acceleration
- Top Speed
- Luggage Space

Of these, vehicle price and fuel economy are the most important.

Nonvehicle attributes that are important factors in a consumer's decision to purchase new vehicle technologies include the following:

- Fuel Price
- Fuel Availability

1.3 Methodology and Calculations

The factors listed above include the factors used in the modeling of new vehicle technology penetration by the NEMS and MARKAL models. ATV attributes and other factors are discussed below.

1.3.1 ATV Attributes: General

ATV attributes were developed based on the FCVT program goals, discussions with FCVT program managers, Powertrain Systems Analysis Toolkit (PSAT) modeling and payback analysis (Refs. 1-5). The PSAT model is a simulation model used by DOE to evaluate the fuel economy and performance of light vehicles using various technologies. Section 1.3.2 below discusses the fuel economy estimates developed in this analysis. Payback analysis was used to estimate what the incremental price of ATVs would be (given the fuel economies from the PSAT model) when they become cost competitive with conventional vehicles, a goal of the program. Section 1.3.3 below discusses the price estimates in further detail. Other attributes were based on a review of past GPRA characterizations (e.g., Ref. 6).

Because the NEMS and MARKAL models require different levels of detail, two separate vehicle characterizations are provided. In both cases, most of the attributes are provided as ratios to the vehicle attributes of conventional vehicles. (For NEMS, the $ value of the price increments were provided.) The attributes are for new vehicles in the year listed. **Table F-1** contains the vehicle attributes for ATVs provided for input to the NEMS model. Attributes are provided for all six car size classes and six light truck (LT) classes that NEMS uses.

Table F-2 contains vehicle attributes for ATVs provided as input to the MARKAL model. MARKAL uses only vehicle price and fuel economy attributes. MARKAL does not disaggregate cars and light trucks into various classes.

1.3.2 Estimation of ATV MPG Estimates

PSAT model results underlie the fuel economy and cost estimates that serve as input to the GPRA benefits models. This section explains how PSAT results have been used to develop the fuel economy inputs to the GPRA models. While the discussion mentions FCVs (because the same methodology was applied to estimate FCV fuel economy), we do not present the FCV MPG estimates in this appendix.

1. There are two GPRA models: NEMS-GPRA07 and MARKAL-GPRA07. The NEMS-GPRA07 model requires characterization of six cars and six LTs for each technology to 2025. The MARKAL-GPRA07 model requires characterization of an average car and an average LT for each technology to 2050. **Table F-3** summarizes the vehicle classes used in both models.

2. The PSAT model itself only provides fuel economy estimates for 4 of the 12 vehicle classes required by NEMS. The four classes in PSAT are also presented in Table 3. They include compact and midsize cars, a SUV and a pickup. PSAT results for those four classes thus must be adjusted in order to develop the fuel economy estimates required by the GPRA models. This adjustment is made as discussed below using a simple spreadsheet model.

3. Two sets of PSAT results were used in this analysis. One set of PSAT results (new vehicle fuel economies) was provided for five vehicle technologies (advanced gasoline, gasoline HEV, advanced diesel, diesel HEV and FCV) in 3 vehicle classes (midsize car, SUV, and pick-up) in 2 years (2010 and 2020) (3). "Low," "high," and "average" results were provided. The "high" results are the only one of the three sets of results that represent achievement of the goals of the FCVT (and HFCIT) program to 2020 for these three vehicle types. Therefore, we used the

“high” results in our analysis. Because PSAT results were not available for the compact car, we assumed that the “high” results of the midsize cars also apply to the compact cars. We do not use the same fuel economies, but instead use the same ratio or “X” factor of ATV fuel economy relative to the baseline gasoline vehicle fuel economy.

4. For GPRA, estimates need to be developed to 2050. The PSAT results discussed above only extend to 2020. Another set of PSAT results were provided for two vehicle technologies (gasoline HEV and FCV) in 3 vehicle types (compact, midsize car and SUV) in 4 years (2010, 2020, 2035, and 2050) (4). Again, “low” and “high” results were provided. Using the “high” results, we estimated the improvement rate in fuel economy from 2020 to 2035, and 2035 to 2050 for the midsize car and SUV for these two technologies. We then applied the improvement rates for the gasoline HEV to the 2020 estimates developed in No. 3 (midsize car to midsize and compact car and SUV to SUV and pickup) to generate new vehicle fuel economy estimates to 2050 for all the technologies (except the FCV).

5. The payback analysis discussed below uses on-road vehicle fuel economy. We assume a 20% degradation factor between the new vehicle fuel economy estimates generated by PSAT and the fuel economies actually achieved “on-road.” (The NEMS and MARKAL models also make this assumption.) This fuel economy degradation factor is then applied to the new vehicle fuel economies developed in No. 3 and No. 4 for ATVs.

6. The PSAT results are developed relative to current gasoline vehicles. EIA projects improvements in conventional gasoline vehicles. The NEMS-GPRA07 and MARKAL-GPRA07 models assume such improvements. We applied EIA’s rate of improvement to the current gasoline vehicles modeled in PSAT and developed new vehicle and on-road fuel economies for the four conventional vehicle types characterized so far (midsize car, SUV, pickup and compact car.) For 2025 to 2050, we used EIA’s 2020-2025 improvement rate.

7. Given the new vehicle fuel economies developed for advanced technologies in No. 5 and for comparable conventional vehicles in No. 6, the final fuel economy ratios (X factors) for those five technologies (advanced gasoline, gasoline HEV, advanced diesel, diesel HEV and FCV) in four vehicle types (compact -car, midsize car, SUV, and pick-up) in several years (2010, 2020, 2025, 2030, 2035, and 2050) are estimated.

8. For the NEMS model, the new vehicle fuel economy X factors of the compact cars are assumed to apply to the mini-compact, subcompact and two-seater as well as the compact. The new vehicle fuel economy X factors of the midsize cars apply to medium and large cars. The new vehicle fuel economy X factors of the SUV (which is a large SUV according to the NEMS classification) are assumed to apply to large and small SUVs and all vans. The new vehicle fuel economy X factors of the pickup (which is a large pickup according to the NEMS classification) are assumed to apply to both small and large pickups.

9. The fuel economy estimates finalized in No. 7 and No. 8 are for the years 2010, 2020, and 2025. For the NEMS model we need to provide estimates for intervening years. For those intervening years, we use linear interpolation to estimate the X factors.

10. As stated above, the MARKAL model uses only one car and one light truck. We examined current sales volumes of the six different car and six different LT types. Based on that examination, we weighted the compact and midsize cars 50-50 to estimate the fuel economy X factors of an average car and we weighted the SUV and pickup 67-33 to estimate the fuel economy of an average LT.

1.3.3 Incremental Vehicle Price Estimates

As indicated above, payback analysis was used to estimate what the incremental price of ATVs would be when they become cost competitive with conventional vehicles, a goal of the program. The incremental price equals the present value of the energy cost reduction achieved by ATVs over three years, assuming a fuel price of $1.50/gallon gasoline equivalent and 7.5% discount rate. Incremental prices are higher in the early years of market introduction. In fact, we develop three sets of prices for each class of vehicle for input to NEMS. Prices are developed for a “market introduction” date, a “price success” date and a “price maturity” date. The price at “price maturity” is the “final” incremental price; the price at “market introduction” is 50% higher than it would be if the technology were “mature” and the price at “price success” is 10% higher than it would be if the technology were “mature.” These dates vary for the different technologies.

For MARKAL, we weight the incremental prices estimated for each technology in 2025 in the same manner that we weighted the fuel economy estimates as described in No. 10 of Section 1.3.1. We then assume a gradually declining incremental price to 2050 for each technology.

1.3.4 ATV Market-Penetration Methodology

Brief descriptions of how the NEMS and MARKAL models each project new vehicle technology penetration using these vehicle attributes can be found in **Chapter 2** (NEMS-GPRA07) and **Chapter 3** (MARKAL-GPRA07).

1.4 Sources

1. “Strategic Plan,” U.S. Department of Energy Efficiency and Renewable Energy, DOE/GO-102002-1649 (October 2002).

2. PSAT (POWERTRAIN SYSTEM ANALYSIS TOOLKIT): see http://www.transportation.anl.gov/software/PSAT/

3. Phillip Sharer and Aymeric Rousseau, “PSAT Results for GREET and GPRA – FE Adjusted 081705.xls”, August 17, 2005.

4. Rousseau, Aymeric, “Number Associated with Presentation”, July 6, 2005.

5. Payback model developed by Jim Moore, TA Engineering (2003) and expanded by Margaret Singh, ANL (2005).

6. “Program Analysis Methodology: Office of Transportation Technologies, Quality Metrics 2003 Final Report”, prepared by OTT Analytic Team, for Office of Transportation Technologies, U.S. Department of Energy (March 2002).

Table F-1. ATV Attributes Input to NEMS
All units are ratios to the conventional gasoline vehicles of the specific year, except for the incremental price (which is in 2003 dollars)

	2-SEATER				MINI-COMPACT				SUB-COMPACT				COMPACT			
	Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity	
Advanced Diesel	**2014**	**2019**	**2024**	**2025**	**2018**	**2023**	**2025**	**N/A**	**2012**	**2017**	**2022**	**2025**	**2011**	**2016**	**2021**	**2025**
Incremental Vehicle Price ($)	1266	984	900	902	1280	956	925		1003	788	738	742	1001	788	750	753
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20		1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	1.00	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.41	1.47	1.49	1.49	1.45	1.49	1.49		1.39	1.44	1.48	1.49	1.38	1.43	1.48	1.49
Diesel Hybrid	**2016**	**2021**	**2025**	**N/A**	**2020**	**2025**	**N/A**	**N/A**	**2016**	**2021**	**2025**	**N/A**	**2014**	**2019**	**2024**	**2025**
Incremental Vehicle Price ($)	1843	1414	1303		1871	1360			1509	1160	1072		1480	1167	1066	1067
Range	1.25	1.25	1.25		1.25	1.25			1.25	1.25	1.25		1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05		1.05	1.05			1.05	1.05	1.05		1.05	1.05	1.05	1.05
Acceleration	1.00	1.00	1.00		0.90	0.90			0.90	0.90	0.90		0.90	0.90	0.90	0.90
Top Speed	1.00	1.00	1.00		0.90	0.90			0.90	0.90	0.90		0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95		0.95	0.95			0.95	0.95	0.95		0.95	0.95	0.95	0.95
Fuel Economy	1.75	1.86	1.87		1.86	1.87			1.75	1.86	1.87		1.70	1.83	1.87	1.87
Gasoline Hybrid	**2013**	**2018**	**2023**	**2025**	**2011**	**2016**	**2021**	**2025**	**2010**	**2014**	**2019**	**2025**	**2007**	**2012**	**2017**	**2025**
Incremental Vehicle Price ($)	1370	1116	1042	1043	1245	1035	1010	1009	1023	840	847	858	1057	805	825	871
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel Economy	1.45	1.56	1.61	1.61	1.41	1.52	1.60	1.61	1.39	1.47	1.58	1.61	1.39	1.43	1.54	1.61

Table F-1 (continued)

	MEDIUM CAR				LARGE CAR			
	Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity	
Advanced Diesel	**2010**	**2015**	**2020**	**2025**	**2009**	**2014**	**2019**	**2025**
Incremental Vehicle Price ($)	1113	882	851	848	1216	935	903	905
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.36	1.42	1.48	1.49	1.36	1.41	1.46	1.49
Diesel Hybrid	**2014**	**2019**	**2024**	**2025**	**2014**	**2019**	**2024**	**2025**
Incremental Vehicle Price ($)	1682	1324	1205	1205	1808	1419	1287	1286
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel Economy	1.70	1.83	1.87	1.87	1.70	1.83	1.87	1.87
Gasoline Hybrid	**2006**	**2011**	**2016**	**2025**	**2009**	**2014**	**2019**	**2025**
Incremental Vehicle Price ($)	1200	888	917	983	1281	1037	1042	1048
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	1.00	0.90	0.90	0.90
Luggage Space	0.85	0.95	0.95	0.95	0.85	0.95	0.95	0.95
Fuel Economy	1.39	1.41	1.51	1.61	1.39	1.47	1.58	1.61

Table F-1 (continued)

	SMALL SUV				LARGE SUV				SMALL TRUCK				CARGO (Incl. 2b) TRUCK			
	Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity	
Advanced Diesel	**2008**	**2013**	**2018**	**2025**	**2007**	**2012**	**2017**	**2025**	**2008**	**2013**	**2018**	**2025**	**2006**	**2011**	**2016**	**2025**
Incremental Vehicle Price ($)	2018	1455	1293	1298	2518	1827	1615	1607	1346	1057	1049	1113	1701	1233	1241	1352
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.75	1.75	1.74	1.78	1.75	1.75	1.74	1.78	1.43	1.48	1.56	1.64	1.43	1.44	1.53	1.64
Diesel Hybrid	**2011**	**2016**	**2021**	**2025**	**2015**	**2020**	**2025**	**N/A**	**2012**	**2017**	**2022**	**2025**	**2016**	**2021**	**2025**	**N/A**
Incremental Vehicle Price ($)	2314	1704	1553	1555	2897	2116	1926		2034	1528	1419	1426	2537	1894	1767	
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20		0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Maintenance Cost	1.05	105	1.05	1.05	1.05	1.05	1.05		1.05	1.05	1.05	1.05	1.05	1.05	1.05	
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00		0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00		0.80	0.90	0.90	0.90	0.80	0.90	0.90	
Fuel Economy	1.99	2.02	2.06	2.10	2.01	2.05	2.10		1.83	1.90	1.97	2.00	1.89	1.95	2.00	
Gasoline Hybrid	**2007**	**2012**	**2017**	**2025**	**2008**	**2013**	**2018**	**2025**	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	1984	1479	1374	1401	2530	1858	1714	1735	1568	1250	1211	1236	1918	1530	1477	1502
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.95	1.00	1.00	0.80	0.95	1.00	1.00
Fuel Economy	1.75	1.77	1.82	1.89	1.75	1.78	1.83	1.89	1.54	1.63	1.71	1.76	1.54	1.63	1.71	1.76

Table F-1 (continued)

	MINIVAN				LARGE VAN			
	Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity	
Advanced Diesel	**2008**	**2013**	**2018**	**2025**	**2006**	**2011**	**2016**	**2025**
Incremental Vehicle Price ($)	1914	1393	1245	1258	2538	1775	1574	1547
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.75	1.75	1.74	1.78	1.75	1.75	1.74	1.78
Diesel Hybrid	**2013**	**2018**	**2023**	**2025**	**2012**	**2017**	**2022**	**2025**
Incremental Vehicle Price ($)	2221	1642	1505	1508	2804	2051	1861	1854
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.09	1.05	1.05	1.05	1.09	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Fuel Economy	2.00	2.03	2.08	2.10	1.99	2.03	2.07	2.10
Gasoline Hybrid	**2009**	**2014**	**2019**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	1903	1432	1335	1358	2416	1813	1668	1670
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.75	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.75	1.79	1.84	1.89	1.75	1.80	1.85	1.89

Table F-1 (continued)

Advanced Gasoline	2-SEATER 2010	2-SEATER 2015	2-SEATER 2020	2-SEATER 2025	MINI-COMPACT 2010	MINI-COMPACT 2015	MINI-COMPACT 2020	MINI-COMPACT 2025	SUB-COMPACT 2010	SUB-COMPACT 2015	SUB-COMPACT 2020	SUB-COMPACT 2025	COMPACT 2010	COMPACT 2015	COMPACT 2020	COMPACT 2025
Incremental Vehicle Price ($)	283	449	581	588	271	432	561	569	230	367	477	484	233	371	483	491
Range																
Maintenance Cost																
Acceleration																
Top Speed																
Luggage Space																
Fuel Economy	1.07	1.16	1.26	1.27	1.07	1.16	1.26	1.27	1.07	1.16	1.26	1.27	1.07	1.16	1.26	1.27

Advanced Gasoline	MEDIUM CAR 2010	MEDIUM CAR 2015	MEDIUM CAR 2020	MEDIUM CAR 2025	LARGE CAR 2010	LARGE CAR 2015	LARGE CAR 2020	LARGE CAR 2025
Incremental Vehicle Price ($)	258	419	546	551	278	450	584	588
Range								
Maintenance Cost								
Acceleration								
Top Speed								
Luggage Space								
Fuel Economy	1.07	1.16	1.26	1.27	1.07	1.16	1.26	1.27

Table F-1 (continued)

	SMALL SUV				LARGE SUV				SMALL TRUCK				CARGO (Incl. 2b) TRUCK			
Advanced Gasoline	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	991	759	714	705	1242	946	887	873	627	649	732	730	767	794	893	886
Range																
Maintenance Cost																
Acceleration																
Top Speed																
Luggage Space																
Fuel Economy	1.27	1.29	1.31	1.31	1.27	1.29	1.31	1.31	1.16	1.25	1.34	1.34	1.16	1.25	1.34	1.34

	MINIVAN				LARGE VAN			
Advanced Gasoline	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	944	729	690	684	1201	917	858	841
Range								
Maintenance Cost								
Acceleration								
Top Speed								
Luggage Space								
Fuel Economy	1.27	1.29	1.31	1.31	1.27	1.29	1.31	1.31

Table F-2. ATV Attributes for Input to MARKAL
(Units are ratios to the conventional gasoline vehicles of the specific year. Prices are in 2003 dollars.)

Ratios to Conventional Vehicles

		2010	2020	2025	2030	2035	2050
CARS							
Advanced Gasoline	MPG	1.07	1.26	1.27	1.29	1.31	1.30
	Incremental Price			1.022			1.019
Diesel	MPG	1.36	1.48	1.49	1.51	1.53	1.64
	Incremental Price			1.033			1.029
Gasoline HEV	MPG	1.39	1.60	1.61	1.64	1.66	1.77
	Incremental Price			1.039			1.020
Diesel HEV	MPG	1.59	1.86	1.87	1.90	1.93	2.06
	Incremental Price			1.047			1.030
LIGHT TRUCKS							
Advanced Gasoline	MPG	1.23	1.32	1.32	1.32	1.32	1.25
	Incremental Price			1.027			1.024
Diesel	MPG	1.64	1.69	1.73	1.77	1.81	1.82
	Incremental Price			1.045			1.028
Gasoline HEV	MPG	1.68	1.80	1.85	1.89	1.94	1.94
	Incremental Price			1.05			1.025
Diesel HEV	MPG	1.92	2.01	2.07	2.12	2.17	2.17
	Incremental Price			1.056			1.029

Table F-3. Vehicle Classes Used in Various Models

	Car Classes						Light Truck Classes					
MARKAL	Cars						Light Trucks					
NEMS	2-seater	Mini-compact	Sub-compact	Compact	Medium	Large	Small SUV	Large SUV	Small Truck	Cargo Truck	Minivan	Large Van
PSAT				Compact	Midsize			SUV		Pick-up		

2.0 Heavy Vehicle Benefits Analysis Introduction

The following sections describe the approach to estimating the fuel economies, incremental costs, and market penetration of heavy vehicles resulting from the Heavy Vehicle Technologies activities of the FreedomCAR and Vehicle Technologies Program of EERE, which are then provided as inputs to the NEMS and MARKAL models. It also describes how the oil savings benefits of these activities are estimated at a detailed level that the NEMS and MARKAL models cannot provide. The scope of the effort includes:

- Characterizing baseline and advanced technology vehicles for **Class 3–6 and Class 7 and 8 trucks**. Gross Vehicle Weights for these vehicle classes are as follows (Ref. 1):
    - Class 310,001 – 14,000 lbs
    - Class 4: 14,001 – 16,000 lbs
    - Class 5: 16,001 – 19,500 lbs
    - Class 6: 19, 501 – 26,000 lbs
    - Class 7 : 26,001 – 33,000 lbs
    - Class 8: 33,001 lbs and up.
- Identification of technology goals associated with the DOE EERE programs,
- Estimating the market potential of technologies that improve fuel efficiency and/or use alternative fuels,
- Determining the petroleum savings associated with the advanced heavy vehicle technologies. These estimates are developed at the program element level to assist project prioritization by the FCVT program. These savings are slightly different from the savings generated by NEMS and MARKAL.

In FY05, the Heavy Vehicles program activity expanded its technical involvement to more broadly address various sources of energy loss as compared to focusing more narrowly on engine efficiency and alternative fuels. This broadening of focus has continued in the activities planned for FY07. These changes are the result of a planning effort that occurred during FY04 and FY05 (Ref. 2).

This narrative describes characteristics of the heavy truck market as they relate to the analysis and provides a description of the analysis methodology—including a discussion of the models used to estimate market potential and benefits. The market penetration of advanced heavy vehicle technologies estimated here is then modeled as part of the EERE-wide integrated analysis (using NEMS and MARKAL) to provide final benefit estimates reported in the FY07 Budget Request.

2.1 Target Market: Heavy Vehicle Target Market

"Heavy Vehicles" are defined in this analysis as including Classes 3 through 6 (Medium Trucks) and Classes 7 and 8 (Heavy Trucks). The Heavy Truck classes are further subdivided by end-use types: i.e., Long-Haul, Intermediate, and Local Use. Vehicle Inventory and Use Survey (VIUS) data were examined for all vehicles in use and vehicles two years old or less (Ref. 3). The Heavy

Truck vehicle market was then disaggregated into these three end-use types. The specific vehicle configurations grouped in each of the three types have similar patterns of travel and annual vehicle mile usage patterns. The vehicle type segments are made up of the vehicle configurations listed below:

- Local Use (Type 1) – multistop, step van, beverage, utility, winch, crane, wrecker, logging, pipe, garbage collection, dump, and concrete delivery;
- Intermediate Use (Type 2) – platform, livestock, auto transport, oil-field, grain, and tank;
- Long-Haul (Type 3) – refrigerated van, drop frame van, open top van, and basic enclosed van.

The lower speed and “stop and start” duty characteristics of Type 1 trucks greatly reduce the potential efficiency benefits in that sector compared to Types 2 and 3. For similar reasons, fuel economy improvements due to other speed-dependent measures such as improved tires will have lower benefit here than in the other two types.

As compared to long distance, over the road travel, Type 2 vehicles tend to be used in a mix of local and regional delivery; and, as a result, will also realize greater fuel economy benefit from aerodynamic improvements than Type 1, but not as great as Type 3. Distances traveled by Type 2 vehicles are typically greater than Type 1, which infers that the typical speeds are higher. These characteristics make them a somewhat better market sector for measures that perform in relation to speed such as advanced tires. In general, Type 3 vehicles are the best candidates for technologies that reduce drivetrain or vehicle losses.

Refueling characteristics; i.e. central-source refueling or non-central source also are considered in the market characteristics, as centrally refueled vehicles would find an alternative fuel source more practical than vehicles that always refuel at road-side facilities.

Eleven travel distance categories for medium trucks and heavy trucks are represented in the model. These categories were determined using travel distributions developed with the VIUS data by Oak Ridge National Laboratory (ORNL) (Refs. 3, 4).

Exhibit 1 shows the distribution of annual travel for Class 3 through 6 and the three types of Class 7 and 8 vehicles. Type 3 vehicles display the greatest amount of annual travel of all heavy vehicle classes as is evidenced in part by the curve’s peaking in the 120,000- to 139,000-mile segment.

Exhibit 2 shows the vehicle use pattern for Local or Type 1 Heavy trucks. The distributions based both on vehicles and vehicle-miles traveled are indicated.

The contrast in distribution by type is evident when Exhibits 2 and 3 are compared. Exhibit 3 shows the same information as Exhibit 2, but for Type 3 trucks. For Type 1, the distribution peaks in the 20,000- to 39,000-mile segment. For Type 3, the peak distribution shows annual travel of 100,000 miles greater than Type 1: 120,000 to 139,000 miles.

Centrally refueled and non-centrally fueled vehicle use characteristics also have been analyzed. Centrally refueled vehicles travel less per year than non-centrally refueled vehicles. In the non-centrally refueled vehicle segment, the majority of travel occurs from 100,000 to 140,000 miles per year. In the central refueling segment, the majority of travel occurs in a more even distribution between 20,000 and 140,000 miles per year.

Heavy vehicle market characteristics that are pertinent to the analysis are summarized in Exhibit 4. In the medium truck market segment (Classes 3 through 6), all vehicle types, with the exception of auto transport, travel about 20,000 miles per year on average. Heavy trucks, depending on type, travel an average of 40,000 miles to 92,000 miles per year. The base fuel economy for all 3 truck types was updated using VIUS 2002 data (Ref. 5).

2.2 Key Factors Shaping Market Adoption of Technology

Based on a survey conducted by the American Trucking Associations in 1997, energy-conservation purchase decisions for this sector are significantly affected by economic viability—specifically the payback of the investment (Ref. 6). The survey of 224 motor carriers revealed that paybacks of one to four years were acceptable for energy-conserving technologies. Based on those findings, we model the market acceptance of the various technologies based on payback performance.

2.2.1 Effects of Lower Emissions on Heavy Vehicle Fuel Economy

The Environmental Protection Agency (EPA) has initiated regulation of emissions from Heavy Trucks. This is changing engine technology and diesel fuel refining. Some reduction in fuel economy with the new engines is also expected as the combustion process optimization is addressing reduction of emissions. Normally, a requirement for reduced emissions will cause a decline in fuel economy. These changes will impose both operating and capital costs on truck operators.

One such EPA rule addressed Ultra-low-Sulfur Diesel (ULSD). The ULSD rule is designed to lower the sulfur content of transportation diesel fuel produced by refineries by 2007. The content of other pollutants, including Nitrogen Oxides (NO_X), Particulate Matter (PM) and Hydrocarbons (HC) are being reduced as well.

These new standards have started to go into effect with 2004 engines and will continue on for model years 2007 and 2010 for highway vehicles, and later for other applications. Major elements of these rules include the following:

- Reduce nitrogen oxides (NOx) and fine particulate matter $PM_{2.5}$ from new heavy-duty highway diesels (e.g., trucks and buses) by about 90%, effective in 2007 for PM, and 2007-2010 for NOx.
- Reduce the sulfur content in highway diesel fuel to 15 ppm ("ultra-low sulfur diesel" fuel, or "ULSD" fuel) beginning in late 2006.
- Reduce nitrogen oxides (NOx) and fine particulate matter $PM_{2.5}$ from new heavy-duty nonroad diesels (e.g., construction, farming and logging equipment) by about 90%, effective in the 2011-2014 time frame depending on the pollutant and the size of engine.
- Reduce the sulfur content in diesel fuel used in stationary engines in two steps, to 500 ppm in 2007 and 15 ppm beginning in 2010.
- Reduce the sulfur content in diesel fuel used in new locomotive and many marine engines in two steps, to 500 ppm in 2007 and 15 ppm beginning in 2012.

The EPA rule-making process includes a cost analysis for the technologies required to meet the new standards. The costs for the new emission control technologies for the 2004 models assumed that fuel injection and turbocharger improvements would happen without the new standards. So in estimating increases in engine costs, the EPA excluded 50% of the technology cost from the total estimated cost. The incremental costs for heavy-duty engines were estimated at $803 in 2004, decreasing to $368 in 2009. The EPA also estimates the increase in annual operating cost for heavy-duty engines to be $104 for the maintenance of the exhaust gas recirculation (EGR).

The effect of additional equipment that is used for treating emissions was also considered. The added weight of the equipment requires additional horsepower output from the engine, which results in a reduction in fuel efficiency. The EPA expects NOx adsorbers to be the most likely emission control technology applied by the industry. NOx adsorber regeneration will require small injections of diesel fuel for "light off" and desorption of stored NO for downstream catalysis under rich-burn conditions. This could result in additional fuel use beyond combustion for propulsion of 2-4%, depending on system maturity. The majority of the reduction in efficiency is associated with the control of sulfur-containing emissions (Ref. 7-9).

2.3 Methodology and Calculations: Overview

The analysis of the benefits expected from achieving the Heavy Vehicle technologies program goals was developed based on four primary reference sources:

- Technology energy efficiency and fuel-use characteristics—as provided by the managers of the technology programs;
- Vehicle characteristics and use information—as obtained from the 1997 VIUS. This provides information on both vehicle performance characteristics, such as fuel economy, and vehicle-use patterns such as miles traveled per year (Ref. 3);
- Truck operator investment requirements—as provided by a survey of Owner-Operators performed by the American Trucking Associations in 1995 (Ref. 6);
- Important "background" information such as energy prices and baseline technology fuel economies—as provided in the Annual Energy Outlook (Reference Case) prepared by the Energy Information Administration (Ref. 10). This information is used in the market penetration methodology which is needed to estimate future fuel economies.

The methodology involves the definition of the energy conservation or displacement and cost attributes of the advanced technologies being fostered by the program, the characterization of the markets affected, and the estimation of the benefits. Several models are used. Specifically, initial benefits estimates are generated through the linkage of four spreadsheet models: (Refs 11-12).

- HTEB - Heavy Truck Energy Balance Model (Version 2.0)
- TRUCK 2.0 - Heavy Vehicle Market Penetration Model
- VISION 2005, and
- Heavy Truck Summary (HVS) report generator.

The relationship of these four models is indicated in **Exhibit 5.**[1] Cost estimates are developed separately.

The **Heavy Truck Energy Balance Model** (HTEBM) was developed to assess the overall fuel economy effect of several changes to the vehicle involving both the engine and other elements of the vehicle. It takes into account energy losses based on user selected inputs of vehicle use. It is a steady-state model. It was required as a result of the lack of existence of publicly available vehicle simulation tool. The fuel economies of new advanced heavy vehicle technologies estimated with the HTEB model are presented in **Exhibit 6.**

The price estimates for these vehicles are also presented in **Exhibit 6.** All prices are in 2003 dollars. Technology cost is not really estimated, any assumed added cost is selected to have a two year payback. As an example, the price schedule for the **Exhibit 6** technologies in the Long Haul vehicle application is indicated in **Exhibit 7**. This process was replicated for Medium Trucks to develop similar cost estimates.

The values for fuel economy improvement from HTEBM and cost are then input to **TRUCK 2.0.** This model was developed to estimate the potential market impacts of new technologies on the medium and heavy truck market. The results generated by this model are:

- Market penetrations, in units of percent of new vehicles sold for each type and class of vehicle, and
- Composite fuel economy rating (new mpg) of the vehicles sold, for each truck type.

As discussed, the TRUCK 2.0 model estimates market penetration based on the cost-effectiveness of the new technology. Cost-effectiveness is measured as the incremental cost of the new technology less the expected energy savings of that technology over a specified time period in relation to specified payback periods.

Exhibit 8 shows the payback distribution assumed in the TRUCK model. This payback distribution was generated from the American Trucking Association's survey described above (Ref. 6). The survey found that, for example, 16.4% of the truck operators responding require a payback of one year on an investment. The TRUCK model market penetration calculation method for Class 7 and 8, Type 1 vehicles is described in **Exhibit 9.**

The market penetration results are supplied through a link to the **VISION** model (Ref. 11). The VISION model is used to estimate preliminary or first order oil/energy use and CO_2 emissions from highway vehicles through 2050 by program element. It contains a baseline estimate of heavy vehicle energy use to 2050. Through 2025 that baseline is the same as that of the AEO.

[1] The HTEB was developed by William Shadis and James Moore of TA Engineering. The TRUCK (2.0) Model was developed as a collaborative effort, initially by John Maples of Oak Ridge National Laboratory (ORNL), with assistance from James Moore, of TA Engineering, Inc. Subsequent enhancements have been performed by Shadis and Moore (TA Engineering). The Vision model was developed by Maples, Anant Vyas and Margaret Singh of ANL. The Heavy Truck Summary Model is a report generating spreadsheet. It was initially developed by Maples, and has subsequently been modified by TA Engineering.

For the period from 2026 to 2050 the baseline energy use is very similar to that of MARKAL. By inputting the market penetration and fuel economy of the advanced heavy vehicle technologies into the model, an alternative estimate of future heavy vehicle energy use is generated and benefits relative to the baseline can be estimated.

Since VISION does not disaggregate Types 1-3 Heavy Trucks or Hybrid-Non-hybrid Medium Trucks, the fuel economy multipliers generated by Truck 2.0 are aggregated on both a sales and VMT-weighted basis for input to VISION. These aggregated fuel economy multipliers are provided in **Exhibit 10**. They are also adjusted to take into account differences in baseline fuel economies provided in VIUS (used in TRUCK 2.0) and the AEO (used in VISION). These factors and the market penetration estimates also presented in Exhibit 10 are the factors ultimately used in the EERE-wide integrated analysis. **More specifically, the factors in cells that are highlighted in yellow are provided for input to the NEMS and MARKAL models.**

Finally, the **Heavy Truck Summary** report generator summarizes the first order benefits for the period covering 2000 through 2050. Benefits (that are used by the FCVT program) include the following:

- Heavy Truck Petroleum Use and Savings, by Class 3-6 and Class 7-8, Million BPD
- Heavy Truck Petroleum Savings - %
- Class 7&8 Truck Savings by Program Element (Technology), Million BPD
- Local Use Truck Savings by Program Element (Technology), Million BPD
- Intermediate Truck Savings by Program Element (Technology), Million BPD
- Long-Haul Truck Savings by Program Element (Technology), Million BPD.

These first order benefits have been generated and will be reported in a forthcoming report. The benefits by FreedomCAR Program Element can not be generated by the NEMS and MARKAL models, and are, therefore, generated by the TRUCK and VISION models.

2.4 Heavy Truck Energy Use Models: Workbooks, Inputs and Outputs

Specific workbooks used in the modeling system are listed below. **Exhibit 11** provides a detailed view of the relationships among the four principal models. In practice, calendar dates indicating times of use are added to the file names for specific Energy Benefits analysis exercises, but these are omitted in this discussion.

1. Heavy Truck Energy Balance Model (HTEBM)-Version 2.0
    - Energy Balance Workbook-Baseline Model
    - Energy Balance Workbook-Technology Model(s) (copied from the Baseline Model)
    - Combined –Effects (used to allocate fuel savings among several technologies).
2. TRUCK (Market Penetration) Models
    - TRUCK-2 Type 1 (projects market penetration of Class 7&8, Type 1 heavy trucks to 2050).

- TRUCK-2 Type 2 (projects market penetration of Class 7&8, Type 2 heavy trucks to 2050).
- TRUCK-2 Type 3 (projects market penetration of Class 7&8, Type 3 heavy trucks to 2050).
- TRUCK-2 Type M (projects market penetration of Classes 3-6 Type heavy trucks to 2050).
- TRUCK-2 Composite (combines all Type 1, 2, 3, M results to obtain summary market penetrations and fleet average fuel economies).

3. VISION MODELS
   - VISION 2005 AEO ICE MPG Base Case (projects energy use of baseline truck fleet to 2050).
   - VISION GPRA0 7Veh.Mi-1 (projects energy use of improved truck fleet to 2050).
4. HvyTrkSum-GPRA-V1 mkt pen veh mi (calculates energy and carbon savings-total heavy truck fleet, classes 3-8, to 2050).

All workbooks should be copied into the same hard-drive subdirectory and all should be loaded so that all of the links are active during the data entry-calculation process.

2.4.1 HTEBM (Heavy Truck Energy Balance Model) Version 2.0

The Heavy Truck Energy Balance Model is based on a simplified calculation of average road loads experienced by typical heavy trucks. It calculates an average fuel economy that balances the truck engine output with the needs to meet engine friction, accessory loads, auxiliary loads and road loads (rolling resistance, aerodynamic resistance, and vehicle braking loads). The model is a method to match baseline vehicles with actual road-load fuel economy results and then to estimate the variations in fuel economy that will occur when various engine and vehicle operational characteristics are changed. Therefore, it is important that actual, simulation-based, or program goals for road-load vehicle fuel economy values be available.

Fuel savings are caused by a combination of technologies-load reducing technologies and engine efficiency-increasing technologies. Each technology under consideration and each analysis year requires a separate run of HTEBM. Since each run includes both input assumptions and results, they need to be maintained for adequate support and documentation.

Engine/Vehicle improvements that lead to reduced fuel use can be categorized under the following headings.

- Increased engine cycle efficiency
  - Increase compression ratio
  - Reduced engine thermal losses
- Reduced engine internal friction loads
  - Air-Breathing Losses
  - Pistons & Piston Rings
  - Rod and crankshaft bearings

- Valve train/camshaft
- Reduced engine accessory loads
  - Fuel Injector
  - Power Steering
  - Oil Pump
  - Coolant Pump
  - Engine fan
- Reduced drive-train parasitic loads
  - Transmission
  - Driveshaft
  - Axle/Transaxle
  - Differential
  - Axle & Wheel bearings
  - Brake Drag
- Reduced vehicle auxiliary system loads
  - Alternator
  - Air Conditioner
  - Air Brake Compressor
- Reduced road-loads
  - Aerodynamic loads
  - Rolling resistance loads
  - Braking loads.

For the Government Performance and Results Act (GPRA), vehicle characteristics to support fuel economy goals at 10-year increments are developed (2010, 2020, 2030, 2040, and 2050).

- **"Combined Effects" Workbook**

The results of the multiple runs of HTEBM are collected in this summary workbook. Whereas HTEBM permits only one set of conditions per-run, "Combined Effects" can store any number of HTEBM results.

The Combined Effects Submodel is used to allocate the fuel savings among the several technologies included in the Truck Technology option. This is done by assuming that the percentage of fuel savings attributable to each separate technology will be proportional to the relative fuel economy improvement of each separate technology, taken separately.

Currently, "Combined Effects" includes four individual heavy vehicle technologies (accessory loads reduction, engine efficiency increase, vehicle weight reduction, and aerodynamic drag reduction). These can be varied to other technologies or Technology Program definitions by the user, if desired.

2.4.2 TRUCK 2.0 Market Penetration Models

The fuel-saving technologies under analysis are characterized in the TRUCK 2.0 models in terms of the projected fuel economy improvement ratio (new fuel economy divided by the baseline fuel economy), the installed cost of the improvement ($ per vehicle), and the cost of the fuel type being used. Market penetration occurs for technologies that meet payback values of 4 years or less. If technology cost information is not available, cost equivalent to a two-year payback is assumed. TRUCK 2.0 can be set to assume the following heavy truck fuels: diesel fuel, gasoline, liquefied propane gas (LPG), ethanol, compressed natural gas (CNG), or electricity (battery storage).

The output from the TRUCK 2.0 Models for each truck Type is a projection of market penetration rates (percent of new vehicle sales) by class and type over the future time from current through year 2050 (or shorter if modeled for a shorter time period). The absolute number of trucks projected to be equipped with the new technology is calculated in the VISION model (see below).

- **"TRUCK Composite" Submodel**

This model collects the market penetration data from the four TRUCK models. It was created as a separate workbook since the TRUCK models are all driven by macros and with distinct inputs. The market penetration and fuel economy results for each of the truck types are linked to this workbook.

2.4.3 VISION Models

- **VISION Base Case Model**

The VISION models accept average new fleet MPG values for Class 3-6 and Class 7 & 8 vehicles and calculate the amount of fuel used each year as these vehicles mature, age and eventually wear out within the operating fleet. Calculations are made for the years 2000 to 2050.

- **VISION Enhanced Case Model**

This version of VISION calculates the fleet energy use assuming that the proposed technologies (fuel savings technologies) are introduced into the new vehicle fleet as calculated by the TRUCK models. Fuel economy and market penetration results from the TRUCK models are consolidated into a single value (for each year to 2050) for Class 7 and 8, and a single value for Classes 3 through 6, using VMT data to weight the fuel economies of each truck Type.

2.4.4 Heavy Truck Summary Submodel (HvyTrkSum)

Key inputs and results of the Truck Model analysis are summarized in the HvyTrkSum workbook. The format used here is intended to meet the needs and requirements of the FutureCar and Vehicle Technologies program, as well as the Planning and Evaluation Office.

HvyTrkSum results form the basis of the GPRA and related reports generated annually presenting the benefits of the Heavy Truck program elements.

2.5 Sources

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11. Singh, M.; A. Vyas, and E. Steiner, "VISION Model: Description of Model Used to Estimate the Impact of Highway Vehicle Technologies and Fuels on Energy Use and Carbon Emissions to 2050," ANL/ESD/04-1 (Dec. 2003).
12. FreedomCAR and Vehicle Technologies Heavy Vehicle Program FY 2006 Benefits Analysis: Methodology and Results -- Final Report. (ANL Report No. 05/60) James Moore, Bill Shadis. TA Engineering, Inc. November 2005.

Exhibit 1: Annual Miles Traveled for Four Truck Categories, 1997

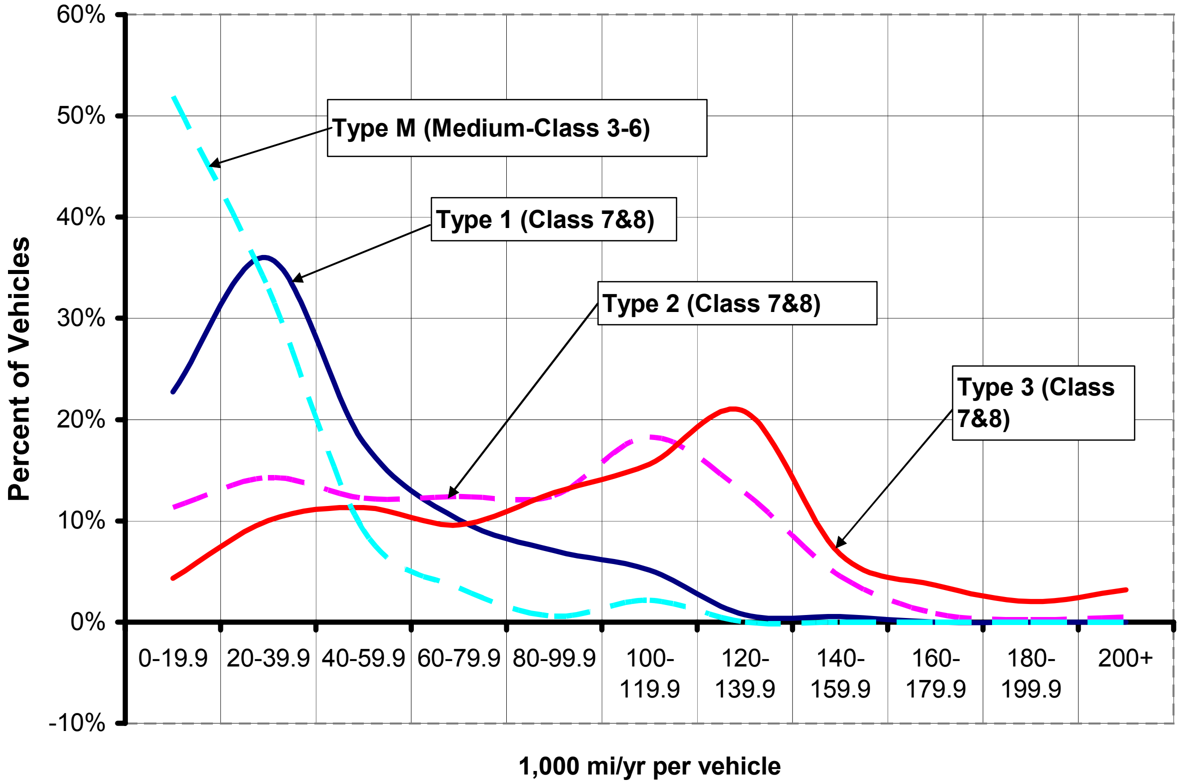

Exhibit 2: Type 1 Vehicle Use

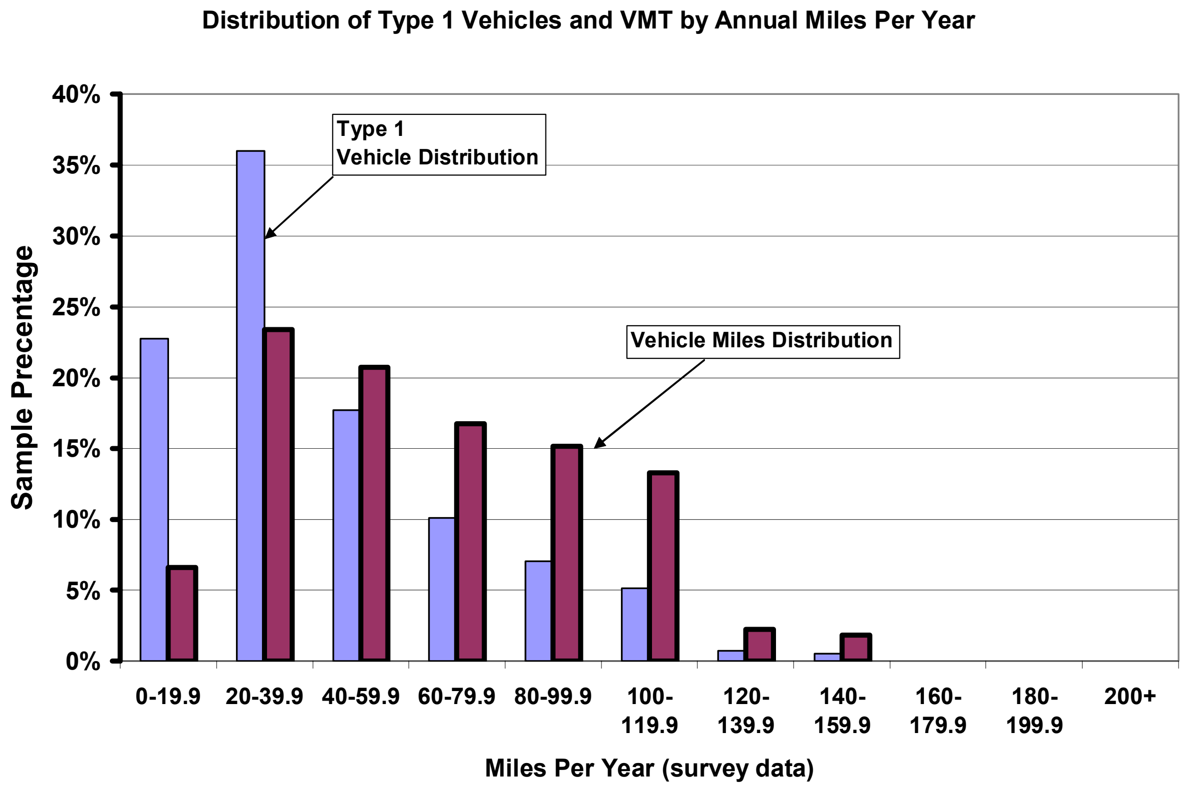

Exhibit 3: Type 3 Vehicle Use

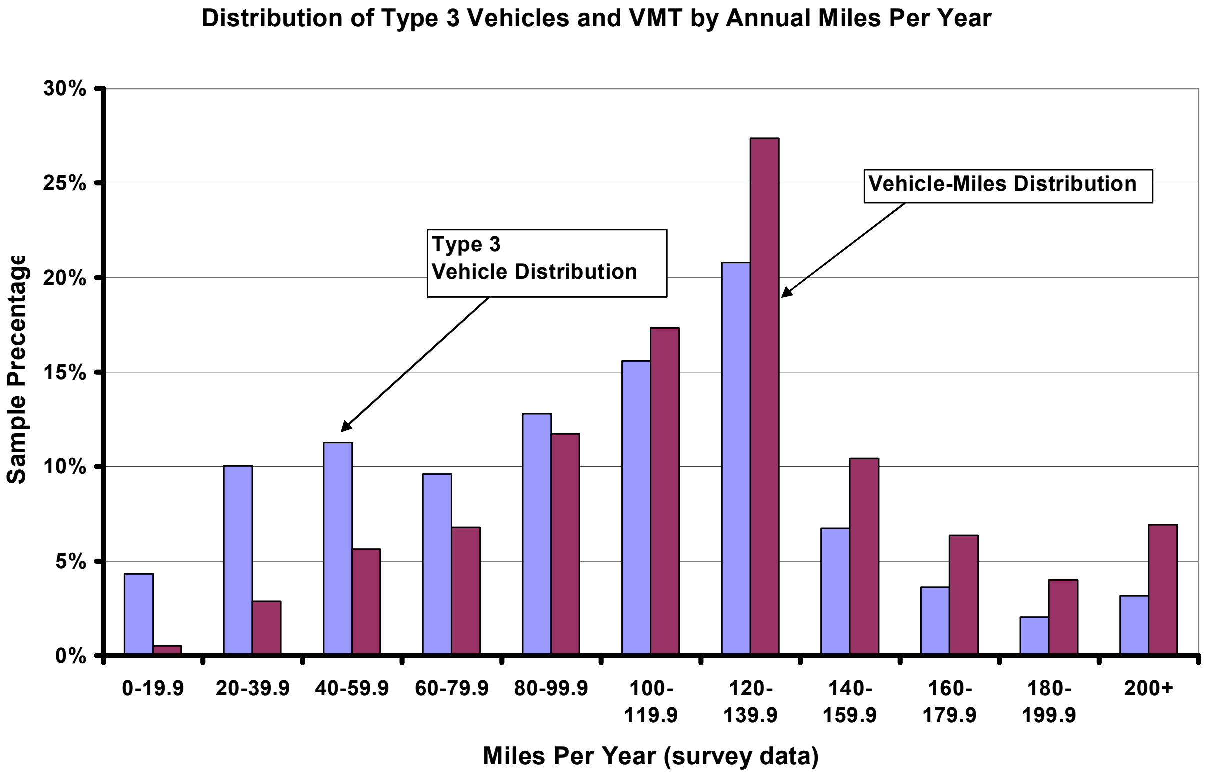

Exhibit 4: Heavy Vehicle Characteristics (1997)

Vehicle Type	Class 7 & 8, Type 1	Class 7 & 8, Type 2	Class 7 & 8, Type 3	Class 3 through 6	Comments
Body Types	**Note 1**	**Note 2**	**Note 3**		
Fuel Economy (Baseline)	5.60	5.60	5.90	8.90	
Fuel Economy Improvement, %	146%	164%	179%	170%	Combined effect of FCVT Technologies, 2020; Class 3 thru 6 is w/o Hybrid
Average Miles Traveled, miles	40,043	74,066	92,434	20,126	
Portion of Heavy Truck Fuel Use, %	11.2%	19.6%	52.9%	4.3%	Estimated--Year 2005
Portion of Vehicle Travel < 50 k Miles,	47%	14.3%	1.6%	73.6%	
Portion of Vehicle Travel 50 k to 100 k	44%	43.5%	35.7%	24.4%	
Portion of Vehicle Travel >100 k	9%	42.2%	53.8%	2.0%	

Note 1: Local Use (Type 1) – multi-stop, step van, beverage, utility, winch, crane, wrecker, logging, pipe, garbage collection, dump, and concrete delivery

Note 2: Intermediate Use (Type 2) – platform, livestock, auto transport, oil-field, grain, and tank;

Note 3: Long-Haul (Type 3) – refrigerated van, drop frame van, open top van, and basic enclosed van.

Exhibit 5: Heavy Truck Benefits Analysis Models

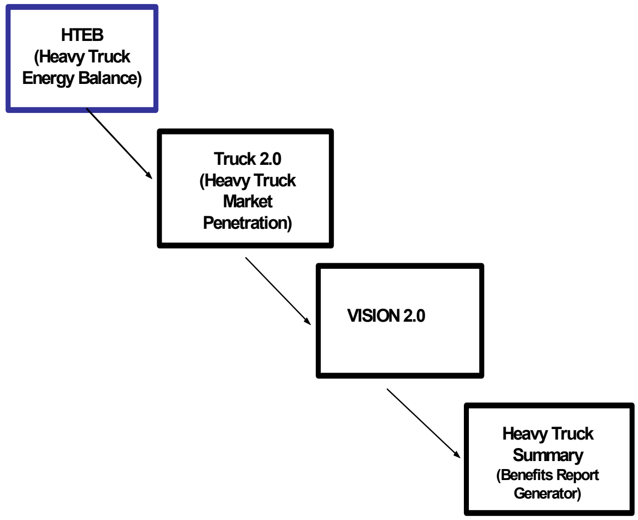

Exhibit 6: Advanced Heavy Vehicle Characterization - New Vehicles (prices are in 2003 dollars)

	Characteristic	2010	2020	2030	2040	2050
1	Fuel Economy Class 7-8, Local Travel (Type 1) mpg Multiplier	1.20	1.51	1.53	1.54	1.54
2	Fuel Economy Class 7-8, Intermediate Travel (Type 2) mpg Multiplier	1.21	1.53	1.56	1.57	1.57
3	Fuel Economy Class 7-8, Long Haul Travel (Type 3) mpg Multiplier	1.25	1.59	1.63	1.63	1.63
4	Fuel Economy Class 3-6- Hybrid, mpg Multiplier	1.41	1.61	1.61	1.61	1.61
5	Fuel Economy Class 3-6- Non-hybrid, mpg Multiplier	1.20	1.46	1.48	1.48	1.48
6	Class 7-8, Iincremental Cost, $	$ 40,000	$ 20,000	$ 10,000	$ 7,000	$ 7,000
7	Class 3-6 Hybrid, Incremental Cost, $	$ 19,000	$ 5,400	$ 2,700	$ 2,700	$ 2,700
8	Class 3-6 Nonhybrid, Incremental Cost, $	$ 5,400	$ 1,700	$ 1,700	$ 1,700	$ 1,700

Exhibit 7: Example Price and Efficiency Schedule for Advanced Technologies (2003 dollars)

Year	Baseline Vehicle Cost ($)	***Non-Hybrid Technologies*** ***Diesel Fuel (only)*** Gross 1st Cost ($)	Efficiency Ratio
2000	150,000	0	1.000
2005	150,000	45,000	1.200
2010	150,000	40000	1.250
2015	150,000	30000	1.350
2020	150,000	20000	1.590
2025	150,000	15000	1.610
2030	150,000	10000	1.630
2035	150,000	7,600	1.630
2040	150,000	7,000	1.630
2045	150,000	7,000	1.630
2050	150,000	7,000	1.630

Exhibit 8: ATA Survey Payback Preference Distribution

Number of Years	Percent of Motor Carriers
1	16.4%
2	61.7%
3	15.5%
4	6.4%

Exhibit 9: Truck Payback Algorithm—Type 1 Trucks

Spreadsheet Location	Description	Comments
Column A	Year	Identifies year for which values, calcuations and results are representative.
Columns B - F	Fuel Economy by Technology	Values are developed based on baseline technology mpg assumptions and efficiency ratios for advanced technologies.
Column G	Cost of Alternative Fuel in $/GGE	Links to Fuel Prices Page
Columns H - I	Calculates annual savings for 2 alternative technologies	For Advanced Diesel: (VMT(C10)x$/GGE/Baseline MPG - VMT x $/GGE/Adv. Diesel MPG)
Columns J - M	Calculates Net Present Value of Savings for 'Advanced Diesel'	Column J: 1 Year, K: 2 years, L: 3 years; M: 4 years
Columns N - Q	Calculates Net Present Value of Savings for 'Alternative Fuel Technology'	Column N: 1 Year, O: 2 years, P: 3 years; Q: 4 years
Columns R - U	If-then Statement to determine 'Cost Effectiveness Factor' (CEF)	If NPV of savings is > Cost of Technology, cell value is (cost - NPVSavings)/Cost; Otherwise cell value is 0. Columns are for paybacks of 1, 2, 3, and 4 years.
Column V	Technology purchase cost 'Alternative Fuel Technology'	Values are linked to Cost values on 'Inputs' page.
Column W - Z	Repeats calcuations in Columns R through U for 'Alternative Fuel Technology'	
Column AA	If-then Statement to determine 'Technology Adoption Factor' (TAF) for 'Advanced Diesel'	If 'Cost Effectiveness Factor' for Year 1 PB is 0, cell value = 100; Otherwise (100-((exp(1995 CE Factor-Current Yr. Factor) - 1)/10 x 100)
Column AB	Continuation of TAF Calculation for Year 1 Payback market	If AA<0, cell value is 1; Otherwise the Value is the same as AA.
Columns AC + AD	Repeat AA and AB for 2 year payback market	
Columns AE + AF	Repeat AA and AB for 3 year payback market	
Columns AG + AH	Repeat AA and AB for 4 year payback market	
Columns AI - AP	Repeat Columns AA through AH methodology for 'Alt. Fuel Technology'	
Column AQ	If-then statement. Start of Market Penetration for 'Advanced Diesel'	If AB = 100, then cell value is 0; Otherwise cell value is (1/(1+Abvalue/exp(-2 x Col. R CEF for 1 Year PB))
Column AR	Same as AQ, but for 2 year PB market.	
Column AS	Same as AQ, but for 3 year PB market.	
Column AT	Same as AQ, but for 4 year PB market.	
Column AU	Final, Step 1; Weighted average market penetration for year 1 through year 4 markets weighting factors	Weighting factors are based on ATA survey results and are listed at the top of Columns AQ-AT.
Column AV	Final, Step 2: Reduces Market Penetration to account for market penetration of 'Atl. Fuel Technology' and stay below 100% share.	=+(AU+(1-BA)*AU)/2
Columns AW - AZ	Same as columns AQ - AT for 'Alterntive fuel technology'.	
Column BA	Final, Step 1; For 'Alt. Fuel Tech.', weighted average market penetration for year 1 through year 4 markets weighting factors	
Column BB	Final, Step 2: Reduces Market Penetration to account for market penetration of 'Atl. Fuel Technology' and stay below 100% share.	
Columns BD - BN	Macro Results Array-Centrally Refueled Advanced Diesels	Central1 Macro results are printed in this part of spreadsheet
BO	Final Step 3: 'Advanced Diesel' (Centrally Refueled) Summation of %VMT that is centrally refueled for the VMT range (e.g. 0-19.9k)* % Market penetration for BD - BN array.	Results are linked to Market Penetration Page
Columns BQ - CA	Macro Results Array-Centrally Refueled Alternative Fuels	Macro results are printed in this part of spreadsheet. Alt Fuel technology only competes in Centrally Refueled Segment
CB	Final Step 3: 'Alt. Fuel' Summation of %VMT that is centrally refueled for the VMT range (e.g. 0-19.9k)* % Market penetration for BD - BN array.	Results are linked to Market Penetration Page
Columns CD - CN	Macro Results Array-Non Centrally Refueled Advanced Diesels	Macro results are printed in this part of spreadsheet
CO	Final Step 3: 'Advanced Diesel' (Non-centrally refueled) Summation of %VMT that is centrally refueled for the VMT range (e.g. 0-19.9k)* % Market penetration for BD - BN array.	Results are linked to Market Penetration Page

Exhibit 10: Advanced Heavy Vehicle Market Penetration and Fuel Economy Results for NEMS Modeling

Year							Class 3 - 6							
	Combined Market Penetration, % VMT	Base MPG (VISION) in gasoline equivalent gallons	Fuel Economy for All New Technology Sales, mpg	Fuel Economy Multiplier only for trucks with new techology which achieve the market penetration shown in Column 2	Estimate of fuel economy for all new 7-8 trucks	Estimate of X factor to input to VISION (only those for 2010, 2020, 2030, 2040 + 2050 are input)	Efficiency, % VMT	Hybrid, % VMT	Combined Market Penetration, % VMT	Base MPG (VISION) in gasoline equivalent gallons	Fuel Economy for All New Technology Sales, mpg	Fuel Economy Multiplier only for trucks with new techology which achieve the market penetration shown in Column 6	Estimate of fuel economy for all new 3-6 trucks	Estimate of X factor to input to VISION (only those for 2010, 2020, 2030, 2040 + 2050 are input)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
2010	0%	5.64	6.97	1.24	5.639	**1.00**	0%	0%	0%	8.54	10.27	1.20	8.54	**1.00**
2011	0%	5.69	7.15	1.27	5.69	1.00	0%	0%	0%	8.55	10.49	1.22	8.55	1.00
2012	0%	5.76	7.34	1.30	5.76	1.00	0%	0%	0%	8.55	10.72	1.25	8.55	1.00
2013	0%	5.85	7.53	1.34	5.85	1.00	0%	0%	0%	8.55	10.94	1.28	8.55	1.00
2014	0%	5.96	7.71	1.37	5.97	1.00	0%	0%	0%	8.55	11.17	1.30	8.56	1.00
2015	1%	6.08	7.90	1.40	6.09	1.00	1%	0%	1%	8.56	11.40	1.33	8.58	1.00
2016	2%	6.12	8.08	1.43	6.15	1.00	1%	0%	1%	8.57	11.62	1.35	8.60	1.00
2017	2%	6.18	8.27	1.47	6.22	1.01	3%	0%	3%	8.58	11.85	1.38	8.65	1.01
2018	4%	6.25	8.46	1.50	6.31	1.01	4%	0%	4%	8.58	12.07	1.41	8.69	1.01
2019	7%	6.25	8.64	1.53	6.36	1.02	13%	0%	13%	8.58	12.30	1.43	8.93	1.04
2020	12%	6.25	8.83	1.57	6.48	**1.04**	15%	0%	15%	8.59	12.53	1.46	9.02	**1.05**
2021	14%	6.26	8.85	1.57	6.53	1.04	17%	0%	17%	8.59	12.54	1.46	9.08	1.06
2022	18%	6.28	8.87	1.57	6.63	1.06	22%	0%	22%	8.59	12.56	1.46	9.24	1.08
2023	21%	6.30	8.89	1.58	6.72	1.07	24%	0%	24%	8.59	12.57	1.47	9.30	1.08
2024	24%	6.31	8.91	1.58	6.79	1.08	23%	1%	24%	8.59	12.59	1.47	9.31	1.08
2025	31%	6.33	8.93	1.58	6.96	1.10	23%	2%	25%	8.59	12.60	1.47	9.34	1.09
2026	32%	6.34	8.95	1.59	7.00	1.10	25%	2%	27%	8.59	12.62	1.47	9.41	1.09
2027	47%	6.36	8.97	1.59	7.37	1.16	29%	3%	32%	8.59	12.64	1.47	9.56	1.11
2028	48%	6.38	8.99	1.60	7.42	1.16	35%	6%	40%	8.59	12.65	1.47	9.87	1.15
2029	59%	6.39	9.01	1.60	7.70	1.21	35%	7%	41%	8.59	12.67	1.48	9.91	1.15
2030	61%	6.41	9.03	1.60	7.78	**1.21**	40%	7%	47%	8.59	12.68	1.48	10.13	**1.18**
2031	62%	6.43	9.04	1.60	7.83	1.22	40%	8%	47%	8.59	12.69	1.48	10.14	1.18
2032	68%	6.44	9.04	1.60	8.00	1.24	36%	12%	48%	8.60	12.69	1.48	10.18	1.18
2033	68%	6.46	9.04	1.60	8.02	1.24	36%	13%	48%	8.60	12.70	1.48	10.19	1.19
2034	70%	6.48	9.05	1.60	8.07	1.25	34%	17%	51%	8.60	12.70	1.48	10.28	1.20
2035	70%	6.49	9.05	1.61	8.11	1.25	29%	25%	54%	8.60	12.71	1.48	10.43	1.21
2036	71%	6.51	9.05	1.61	8.12	1.25	29%	28%	57%	8.60	12.71	1.48	10.55	1.23
2037	71%	6.53	9.06	1.61	8.13	1.25	29%	28%	57%	8.60	12.72	1.48	10.57	1.23
2038	71%	6.54	9.06	1.61	8.15	1.25	29%	29%	58%	8.60	12.72	1.48	10.59	1.23
2039	71%	6.56	9.06	1.61	8.16	1.24	30%	29%	59%	8.60	12.73	1.48	10.63	1.24
2040	71%	6.58	9.07	1.61	8.18	**1.24**	33%	29%	62%	8.60	12.73	1.48	10.76	**1.25**
2041	71%	6.60	9.07	1.61	8.19	1.24	48%	27%	76%	8.60	12.73	1.48	11.39	1.32
2042	72%	6.61	9.07	1.61	8.20	1.24	43%	35%	78%	8.60	12.73	1.48	11.51	1.34
2043	72%	6.63	9.07	1.61	8.21	1.24	41%	38%	79%	8.60	12.73	1.48	11.58	1.35
2044	72%	6.65	9.07	1.61	8.23	1.24	40%	39%	79%	8.61	12.73	1.48	11.58	1.35
2045	72%	6.66	9.07	1.61	8.24	1.24	40%	39%	79%	8.61	12.73	1.48	11.59	1.35
2046	73%	6.68	9.07	1.61	8.27	1.24	40%	39%	79%	8.61	12.73	1.48	11.59	1.35
2047	73%	6.70	9.07	1.61	8.29	1.24	40%	40%	80%	8.61	12.73	1.48	11.59	1.35
2048	74%	6.72	9.07	1.61	8.30	1.24	40%	40%	80%	8.61	12.73	1.48	11.60	1.35
2049	74%	6.73	9.07	1.61	8.31	1.24	40%	40%	80%	8.61	12.73	1.48	11.61	1.35
2050	74%	6.75	9.07	1.61	8.33	**1.23**	41%	40%	81%	8.61	12.73	1.48	11.65	**1.35**

Exhibit 11: Heavy Truck Energy Modeling System Details