Appendix J – GPRA05 Vehicle Technologies Program Documentation

Light-Vehicle Characterization

Light-vehicle (LV) attributes were based on the FreedomCAR and Vehicle Technologies (FCVT) program goals, discussions with FCVT program managers, and technical analysis by contractors (Ref. 1). They were also based on a review of past GPRA characterizations (e.g., attributes included in the 2003 GPRA transportation methodology report that can be found on the EERE Web site (Ref. 2). Because the two models (NEMS-GPRA05 and MARKAL-GPRA05) that generate GPRA results require different levels of detail, the technical characterizations were provided in two parts: one for input to NEMS-GPRA05 and one for input to MARKAL-GPRA05. The discussion of the LV characterization is, thus, divided into two parts below.

Input to NEMS-GPRA05

Table 1 contains vehicle attributes for advanced diesels, diesel hybrids, gasoline hybrids, and hydrogen (H2) internal-combustion engines (ICEs). These advanced technologies may be used in cars and light trucks (LTs). Attributes are provided for the four technologies in six car size classes and six LT classes. (H2 ICEs are characterized for fewer classes.) The attributes are for new vehicles in the year listed. The attributes include the following:

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

The attributes for the four technologies are provided as ratios to the vehicle attributes of conventional vehicles. **Table 1** presents the baseline conventional vehicle price and fuel economy attributes assumed for this analysis.

The attributes of the four advanced technologies vary over time. The four technologies are at different stages of technology development and, thus, are expected to penetrate the LV market at different times. Attributes were provided by the FCVT program for each technology/size class at the time of market introduction, at market maturity (generally identified by achievement of fuel economy goals), at price maturity, and for the year 2025. These attributes were implemented in NEMS-GPRA05 as step-functions over time.

Price and fuel economy are the two most important attributes characterized. The incremental price over a conventional vehicle for any vehicle of a specific size class and technology at market maturity is estimated using a three-year payback period. (The incremental price equals

the present value of the energy cost reduction achieved by advanced technology vehicles over three years.) Incremental prices are assumed to be 50% higher at market introduction than at market maturity and 20% lower at price maturity.

Input to MARKAL-GPRA05

The MARKAL-GPRA05 model provides the benefits estimates for the GPRA analysis out to 2050. The model does not require LV characterization at the level of detail that NEMS-GPRA05 does. There is no disaggregation of cars and LTs into size classes and only cost and fuel economy ratios are required. **Table 2** presents the LV characterization input to MARKAL-GPRA05. H2 ICEs are transitional to the more efficient use of H2 in fuel cell vehicles and, thus, are not expected to continue in the market post-2025. Therefore, they are not in **Table 2**.

References

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

2. "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 1: Attributes of Advanced Technology Vehicles Relative to Conventional Vehicles (CV)

	2-SEATER				MINI-COMPACT				SUB-COMPACT				COMPACT			
CV Price (000s) /MPG	43.3/19.1				54.3/19.5				19.4/23.4				19.8/23.1			
	Intro	Market Maturity	Price Maturity		Intro	Market Maturity	Price Maturity		Intro	Market Maturity	Price Maturity		Intro	Market Maturity	Price Maturity	
Advanced Diesel	**2014**	**2019**	**2024**	**2025**	**2012**	**2017**	**2022**	**2025**	**2010**	**2015**	**2020**	**2025**	**2008**	**2013**	**2018**	**2025**
Vehicle Price	1.036	1.024	1.019	1.018	1.028	1.019	1.015	1.013	1.066	1.044	1.035	1.030	1.066	1.044	1.035	1.030
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	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Diesel Hybrid	**2016**	**2021**	**2025**	**N/A**	**2014**	**2019**	**2024**	**2025**	**2012**	**2017**	**2022**	**2025**	**2010**	**2015**	**2020**	**2025**
Vehicle Price	1.072	1.036	1.030		1.045	1.030	1.024	1.023	1.132	1.070	1.056	1.050	1.104	1.069	1.055	1.050
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
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
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	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	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
Fuel Economy	1.60	2.00	2.00		1.70	2.10	2.10	2.10	1.70	2.10	2.10	2.10	1.70	2.10	2.10	2.10
Gasoline Hybrid	**2013**	**2018**	**2023**	**2025**	**2011**	**2016**	**2021**	**2025**	**2009**	**2014**	**2019**	**2025**	**2007**	**2017**	**2017**	**2025**
Vehicle Price	1.065	1.035	1.025	1.022	1.040	1.027	1.022	1.018	1.185	1.063	1.050	1.045	1.094	1.062	1.050	1.040
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	1.60	1.90	1.90	1.90	1.60	1.90	1.90	1.90	1.60	1.90	1.90	1.90	1.60	1.90	1.90	1.90
Hydrogen ICE	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**2014**	**2020**	**2020**	**N/A**
Vehicle Price													1.250	1.150	1.150	
Range													0.55	0.75	0.75	
Maintenance Cost													1.00	1.00	1.00	
Acceleration													0.85	0.95	0.95	
Top Speed													1.00	1.00	1.00	
Luggage Space													0.55	0.75	0.75	
Fuel Economy													1.10	1.20	1.20	

Table 1 (continued)

	MEDIUM CAR				LARGE CAR			
CV Price (000s) /MPG	25.9/20.4				30.3/18.9			
	Intro	Market Maturity	Price Maturity		Intro	Market Maturity	Price Maturity	
Advanced Diesel	**2007**	**2012**	**2017**	**2025**	**2005**	**2010**	**2015**	**2025**
Vehicle Price	1.049	1.033	1.026	1.022	1.045	1.030	1.024	1.018
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	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Diesel Hybrid	**2012**	**2017**	**2022**	**2025**	**2010**	**2015**	**2020**	**2025**
Vehicle Price	1.073	1.049	1.039	1.037	1.068	1.045	1.036	1.030
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	1.50	1.75	1.75	1.75	1.50	1.75	1.75	1.75
Gasoline Hybrid	**2004**	**2009**	**2014**	**2025**	**2004**	**2009**	**2014**	**2025**
Vehicle Price	1.057	1.038	1.030	1.025	1.053	1.035	1.028	1.020
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	0.85	0.95	0.95	0.95	0.85	0.95	0.95	0.95
Fuel Economy	1.35	1.50	1.50	1.50	1.35	1.50	1.50	1.50
Hydrogen ICE	**2012**	**2020**	**2020**	**N/A**	**2010**	**2020**	**2020**	**N/A**
Vehicle Price	1.200	1.150	1.150		1.200	1.100	1.100	
Range	0.48	0.75	0.75		0.50	0.75	0.75	
Maintenance Cost	1.05	0.95	0.95		1.05	0.95	0.95	
Acceleration	0.95	1.00	1.00		1.00	1.00	1.00	
Top Speed	1.00	1.00	1.00		1.00	1.00	1.00	
Luggage Space	0.50	0.75	0.75		0.55	0.80	0.80	
Fuel Economy	1.10	1.15	1.15		1.10	1.15	1.15	

Table 1 (continued)

	MINIVAN				LARGE VAN			
CV Price (000s) /MPG		26.7/18.2				23.0/14.6		
	Intro	Market Maturity	Price Maturity		Intro	Market Maturity	Price Maturity	
Advanced Diesel	**2006**	**2011**	**2016**	**2025**	**2004**	**2009**	**2014**	**2025**
Vehicle Price	1.053	1.035	1.028	1.024	1.054	1.036	1.029	1.025
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	1.40	1.40	1.40	1.40	1.25	1.25	1.25	1.25
Diesel Hybrid	**2011**	**2016**	**2021**	**2025**	**2010**	**2015**	**2020**	**2025**
Vehicle Price	1.080	1.053	1.043	1.025	1.101	1.067	1.054	1.040
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	1.50	1.75	1.75	1.75	1.40	1.60	1.60	1.60
Gasoline Hybrid	**2004**	**2009**	**2014**	**2025**	**2008**	**2013**	**2018**	**2025**
Vehicle Price	1.062	1.041	1.033	1.028	1.054	1.036	1.029	1.025
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	1.35	1.50	1.50	1.50	1.20	1.25	1.25	1.25
Hydrogen ICE	**2010**	**2020**	**2020**		**2008**	**2018**	**2020**	
Vehicle Price	1.200	1.100	1.100		1.250	1.150	1.080	
Range	0.55	0.75	0.75		0.50	0.70	0.75	
Maintenance Cost	1.00	0.95	0.95		1.05	1.00	0.95	
Acceleration	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	
Luggage Space	0.65	0.85	0.85		0.80	0.90	0.92	
Fuel Economy	1.10	1.15	1.15		1.10	1.15	1.15	

Table 1 (continued)

	SMALL SUV				LARGE SUV				SMALL TRUCK				CARGO (Incl. 2b) TRUCK			
CV Price (000s) /MPG	27.7/17.2				35.2/14.1				18.5/18				25.3/15.1			
	Intro	Market Maturity	Price Maturity		Intro	Market Maturity	Price Maturity		Intro	Market Maturity	Price Maturity		Intro	Market Maturity	Price Maturity	
Advanced Diesel	**2004**	**2009**	**2014**	**2025**	**2007**	**2012**	**2017**	**2025**	**2003**	**2008**	**2013**	**2025**	**2003**	**2008**	**2013**	**2025**
Vehicle Price	1.063	1.042	1.034	1.026	1.053	1.035	1.028	1.023	1.084	1.056	1.045	1.038	1.066	1.044	1.035	1.031
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	1.40	1.50	1.50	1.50	1.30	1.40	1.40	1.40	1.40	1.45	1.45	1.45	1.40	1.40	1.40	1.40
Diesel Hybrid	**2011**	**2016**	**2021**	**2025**	**2015**	**2020**	**2025**	**N/A**	**2012**	**2017**	**2022**	**2025**	**2016**	**2021**	**2025**	**N/A**
Vehicle Price	1.084	1.056	1.045	1.036	1.078	1.052	1.035		1.121	1.080	1.064	1.059	1.102	1.068	1.054	
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	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	
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	1.60	1.80	1.80	1.80	1.50	1.75	1.75		1.50	1.80	1.80	1.80	1.50	1.75	1.75	
Gasoline Hybrid	**2004**	**2009**	**2014**	**2025**	**2005**	**2010**	**2015**	**2025**	**2006**	**2011**	**2016**	**2025**	**2007**	**2012**	**2017**	**2025**
Vehicle Price	1.063	1.042	1.034	1.026	1.053	1.035	1.028	1.023	1.091	1.060	1.048	1.040	1.061	1.041	1.033	1.030
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	0.95	0.95	0.80	0.95	0.95	0.95
Fuel Economy	1.35	1.50	1.50	1.50	1.25	1.40	1.40	1.40	1.35	1.50	1.50	1.50	1.25	1.35	1.35	1.35
Hydrogen ICE	**N/A**	**N/A**	**N/A**	**N/A**	**2010**	**2020**	**2020**	**N/A**	**2009**	**2018**	**2020**	**N/A**	**2008**	**2018**	**2020**	**N/A**
Vehicle Price					1.200	1.100	1.100		1.300	1.150	1.100		1.200	1.100	1.060	
Range					0.55	0.75	0.75		0.50	0.70	0.75		0.50	0.70	0.75	
Maintenance Cost					1.00	0.95	0.95		1.00	1.00	0.95		1.05	1.00	0.95	
Acceleration					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	
Luggage Space					0.60	0.82	0.82		0.50	0.72	0.75		0.50	0.75	0.80	
Fuel Economy					1.12	1.15	1.15		1.10	1.15	1.15		1.10	1.15	1.15	

Table 2. Light-Vehicle Characteristics for Analysis of FCVT Program Using MARKAL-GPRA05 Model

Vehicle Type	Technology	Ratio	2010	2020	2030	2040	2050
Car	Gasoline HEV	Cost	1.09	1.05	1.03	1.02	1.01
		MPG	1.50	1.70	1.90	2.00	2.00
	Diesel	Cost	1.07	1.04	1.02	1.02	1.02
		MPG	1.40	1.50	1.50	1.60	1.60
	Diesel HEV	Cost	1.12	1.07	1.05	1.04	1.04
		MPG	1.70	1.90	2.10	2.19	2.27
LT	Gasoline HEV	Cost	1.10	1.06	1.04	1.03	1.02
		MPG	1.35	1.50	1.60	1.62	1.64
	Diesel	Cost	1.08	1.05	1.03	1.02	1.02
		MPG	1.40	1.45	1.50	1.61	1.60
	Diesel HEV	Cost	1.13	1.09	1.07	1.06	1.05
		MPG	1.50	1.75	1.80	1.81	1.82

Heavy-Vehicle Characterization

Introduction

This report describes the approach to estimating benefits and the analysis results for the heavy-vehicle technologies activities of the FreedomCAR and Vehicle Technologies Program of EERE. The scope of the effort included:

- Characterizing baseline and advanced technology vehicles for Class 3 – 6 and Class 7 and 8 trucks,
- 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 and greenhouse gas emissions reductions associated with the advanced technologies.

This narrative contains a description of the analysis methodology, a discussion of the models used to estimate market potential and benefits, and a presentation of the benefits estimated as a result of the adoption of the advanced technologies. These benefits estimates, along with market penetrations and other results, are then modeled as part of the EERE-wide integrated analysis to provide final benefit estimates reported in the FY05 Budget Request.

Background

This analysis of the benefits expected from achieving the program's goals for heavy-vehicle technologies 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 Vehicle Inventory and Use Survey (VIUS). This provides information on both vehicle performance characteristics, such as fuel economy; and also vehicle use patterns such as miles traveled per year (Ref. 1).
- Truck operator investment requirements—as provided by a survey of Owner-Operators performed by the American Trucking Associations in 1995 (Ref. 2).
- Important "background" information, such as energy prices and baseline technology fuel economies, are based on Annual Energy Outlook 2003 (Reference Case) prepared by the Energy Information Administration (Ref. 3).

The methodology involves the disaggregation of heavy-vehicle types according to use patterns. This has enabled the identification of the vehicle types that accumulate the greatest vehicle miles traveled and, therefore, offer the best opportunity for economic viability of an investment in an energy-conserving technology. The market analysis of the heavy-vehicle sector embodied in this analysis is, thus, more robust than is available in NEMS and MARKAL and provides better estimates of the impacts of DOE's heavy-vehicle program.

The market segmentation also identifies travel distributions for heavy vehicles that utilize central refueling sites and those that do not. Central refueling will be more conducive to the introduction of an alternative fuel, because the initial refueling infrastructure required does not have to be as extensive as the alternative-fuel refueling infrastructure, which would be required for vehicles that do not centrally refuel and, thus, should be less costly.

Approach

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.

Technology Characteristics

The heavy-vehicle technologies span engine improvements to improve fuel economy, reduction in parasitic losses—mostly through improved aerodynamics and tire designs, and weight reduction. The programs supporting these technology development efforts focus on Class 7 and 8 trucks—as these truck classes are the dominant fuel users among Classes 3 through 8. Engine fuel economy improvements and weight reduction and hybrid vehicle systems are being developed for application in medium trucks (Classes 3 through 6). Because of differences in the utilization and types of driving conditions among various truck types, the fuel economy improvement opportunities are considered to vary according to truck type. (Truck types are discussed in the Heavy Truck Market Analysis that follows this section.) Technology characteristics are presented in **Table 3.** Ratios are relative to technology characteristics in 2005.

The cost of the technology to buyers at the time of commercialization is difficult (if not impossible) to estimate, because much of the work is in early stages of development. However, due to a survey conducted by the American Trucking Associations in 1997, buyer payback requirements are known (Ref. 2). The survey of 224 motor carriers revealed that paybacks of one to four years were acceptable for energy conserving technologies. Based on those findings, a technology goal for the time of technology commercialization was selected to be the cost that would equate to a two-year payback. Hence, for each of the technology characteristics shown in **Table 3**, payback analyses were performed. The results of one of these analyses are summarized in **Table 4.**

Table 3. Heavy-Truck Inputs for FY 05 GPRA

Class	Type or Technology	Description	2005	2010	2015	2020	2025	2030	2040	2050
7 - 8	3	Over the road: van								
	Engine	8.90 mpg	1	1.05	1.15	1.25	1.33	1.4	1.45	1.50
	Parasitic (aero and tires)	92,500 miles/year	1	1.03	1.13	1.24	1.35	1.45	1.58	1.70
	Weight reduction	59.6% of 7-8 vmt	1	1.01	1.03	1.08	1.11	1.14	1.17	1.20
	Total MPG Multiplier		1	1.092	1.338	1.674	1.993	2.314	2.68	3.06
	2	Regional: open								
	Engine	6.16 mpg	1	1.03	1.07	1.13	1.2	1.25	1.3	1.35
	Parasitic (aero and tires)	74,000 miles/year	1	1.01	1.04	1.08	1.1	1.13	1.15	1.17
	Weight reduction	22.6% of 7-8 vmt	1	1.003	1.01	1.02	1.05	1.07	1.09	1.10
	Total MPG Multiplier		1	1.043	1.124	1.245	1.386	1.511	1.63	1.737
	1	Local operation: heavy-duty								
	Engine	4.55 mpg	1	1.03	1.07	1.13	1.2	1.21	1.22	1.25
	Parasitic (aero and tires)	40,000 miles/year	1	1	1.01	1.02	1.03	1.04	1.05	1.05
	Weight reduction	17.8% of 7-8 vmt	1	1.003	1.01	1.02	1.03	1.04	1.05	1.06
	Total MPG Multiplier		1	1.033	1.092	1.176	1.273	1.309	1.345	1.391
3 - 6		Local operation: medium-duty								
	Engine	8.90 mpg	1	1.03	1.07	1.13	1.2	1.21	1.22	1.25
	Hybrid	20,000 miles/year	1	1.05	1.1	1.15	1.2	1.25	1.3	1.35
	Weight reduction		1	1.003	1.01	1.03	1.05	1.07	1.09	1.10
	Total MPG Multiplier		1	1.085	1.189	1.338	1.512	1.618	1.729	1.856

Source: Reference 4

The case illustrated is for Type 3 technology in 2010. The fuel economy improvement is 9.2%, the baseline fuel economy is 8.9 mpg, and the estimated usage is 92,500 miles/year as indicated in **Table 3.**

As shown in the table on the right in **Table 4** and in the graph, the incremental first cost that equates to the savings during a two-year period is $2,535. Subsequent year costs were estimated, based on the higher fuel-efficiency benefit goal of the program, but also considering production cost reductions as market penetration expands and development costs can be amortized against increasing sales.

The cost schedule for the **Table 3** technologies in the Type 3 vehicle application is indicated in **Table 5**.

This analysis was replicated for Type 1 and Type 2 vehicles and Medium Trucks.

Table 4. Payback Analysis Used to Develop Technology Cost Goal

Inputs (Assumptions--User defined):

Item	Year 1
MPG Multiplier	1.092
Fuel Economy-Conventional, mi/gal.	8.9
Vehicle Miles, mi./yr	92,500
Fuel Cost, $/gal.	$1.50
Discount Rate:	7.5%

Results: Purchase Cost Increase Equivalent to Fuel Savings

Payback, Years	Incremental First Cost, $	Payback Period Distribution, Years	Comments
5	$5,713	6.4%	
4	$4,729	6.5%	
3	$3,672	61.7%	
2	$2,535	15.5%	
1	$1,313	16.4%	

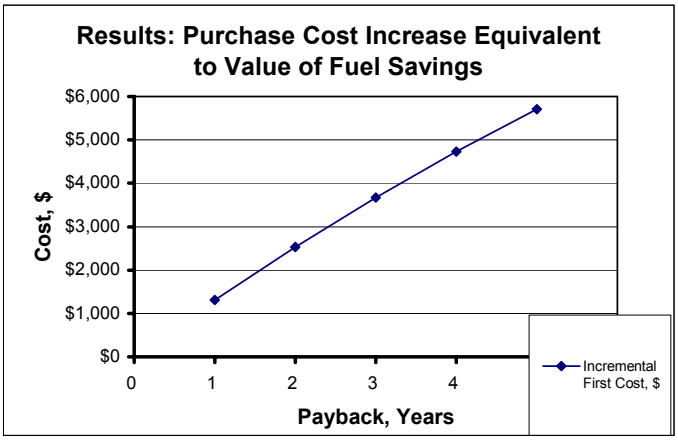

Table 5. Example First-Cost Schedule for Advanced Technologies Type 3 Heavy Trucks

Year	Technology Cost Assumption, $	Two Year Payback Equivalent Cost, $	Comments
2010	2,535	2,535	2-year payback model calculation
2015	3,800	7,606	
2020	6,100	12,116	
2025	5,000	15,000	
2030	3,750	15,000	
2035	3,750	15,000	

Market Segmentation Analysis

As noted above, "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—1, 2, and 3. VIUS data were examined for all vehicles in use and vehicles two years old or less. The Heavy Truck vehicle market was parsed by the Analytic Team into these three types—with each having similar use and annual vehicle mile use patterns. The vehicle type segments are:

- Type 1 – multistop, step van, beverage, utility, winch, crane, wrecker, logging, pipe, garbage collection, dump, and concrete delivery;
- Type 2 – platform, livestock, auto transport, oil-field, grain, and tank;
- 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 of aerodynamic improvements in that sector. For similar reasons, fuel economy improvements due to advanced tires also would be limited for Type 1 vehicles.

As compared to long distance, over the road travel, Type 2 vehicles tend to be used in local or regional delivery; and, as a result, will also realize limited fuel economy benefit from aerodynamic improvements. Distances traveled by Type 2 vehicles are typically greater than Type 1, which makes them a somewhat better market sector for advanced tires.

In general, Type 3 vehicles are the best candidates for both tire and aerodynamic improvement technologies. Refueling characteristics; i.e. central-source refueling or noncentral source also were considered as centrally refueled vehicles would find an alternative fuel source more practical than vehicles that always refuel at road-side facilities.

Heavy vehicle characteristics are summarized in **Table 6**.

Table 6. Heavy-Vehicle Characteristics

Vehicle Type	Average Annual Miles (1)	Fuel Economy (MPG)	Percent Centrally Refueled (1)
Class 3-6	20,126	8.90	40.1%
Class 7 & 8 Type 1	40,043	4.55	59.8%
Class 7 & 8 Type 2	74,066	6.16	41.0%
Class 7 & 8 Type 3	92,434	8.90	42.0%

Note 1: Vehicles 2 years old or less

In the medium-truck market segment (Classes 3 through 6), all vehicle types, with the exception of auto transport, on average, travel about 20,000 miles per year. Heavy trucks, depending on type, travel an average of 40,000 miles to 92,000 miles per year. One of the more interesting findings was the significant difference in fuel economy among the vehicle types with Type 3 heavy vehicles exhibiting an average fuel economy nearly twice as high as Type 1 heavy vehicles (8.90 vs 4.55 MPG).

In addition to the market characterization, historical market penetration data were obtained from VIUS surveys for energy conserving technologies including radial tires, aerodynamic devices, and fan clutches. These data were utilized in the calibration of the rate of efficiency technology adoption in the model (Ref. 1).

Heavy-Vehicle Benefits-Analysis Overview

Initial benefits estimates are generated through the linkage of three spreadsheet models:

- The Heavy Vehicle Market Penetration (HVMP) model
- Integrated Market Penetration And Cost of Transportation Technologies (IMPACTT) model, and
- Heavy Truck Summary (HVS) model.

The relationship of these three models is indicated in **Figure 1**[1].

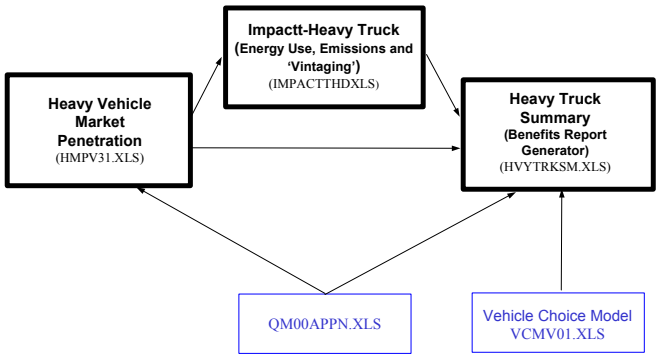

Figure 1.
Heavy-Truck Benefits-Analysis Models

Values for technology performance attributes and cost are input into the Heavy Vehicle Market Penetration (HVMP) model. This includes estimates for current technology fuel economy. Energy prices and projections used in the HVMP are from *AEO 2003*. The HVMP 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

[1] The Heavy Vehicle Market Penetration 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 Moore (TA Engineering).

IMPACTT was originally developed by Marianne Mintz, Argonne National Laboratory (ANL). The version of the model used for the Heavy Vehicle Analyses has been modified by Moore, et al, TA Engineering, with assistance from ANL.

The Heavy Truck Summary Model is a report generating spreadsheet. It was initially developed by Maples, and has subsequently been modified by Analysts at the National Renewable Energy Laboratory, and TA Engineering.

The Quality Metrics Light Vehicle Results Model was developed initially by John Maples, ORNL and has since been modified extensively by Elyse Steiner, NREL and other NREL analysts.

The Vehicle Choice Model is an accounting model developed by Analytic Team members over a period of years.

- Composite fuel economy rating (new mpg) of the vehicles sold.

The market penetration results are supplied through a link to the Impact-Heavy Truck model. This "accounting" and vehicle vintaging model calculates energy savings, criteria and carbon pollution effects, and the rate of market penetration of the new technologies into the entire fleet of Class 3 through 8 trucks.

These interim results are linked to the Heavy Truck Summary model in which various reports of the energy, emissions, and economic benefits attributable to the use of the advanced technologies are calculated. Energy price factors and projections from the Annual Energy Outlook Reference Case are used by the Heavy Truck Summary model to calculate cost savings.

Heavy-Vehicle Market-Penetration Model

The HVMP model market penetration calculation method for Class 7 and 8, Type 1 vehicles is described in **Table A-1** in the appendix. The calculation method for the other three vehicle types and classes is highly analogous.

As discussed above, the HVMP model estimates market penetration, based on 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.

Table 7 shows the payback distribution assumed in the HVMP model. This payback distribution was generated from the American Trucking Associations' survey described above (Ref. 1). The survey found that, for example, 16.4% of the truck operators responding require a payback of one year on an investment.

Table 7. Heavy-Vehicle Payback Period Market Distribution

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

The new-technology cost and the expected efficiency improvements are exogenous inputs in the model. Energy savings are calculated using the following data and assumptions:

- Annual vehicle miles traveled;
- Fuel efficiency (mpg) without new technology;
- Fuel efficiency (mpg) with new technology; these are specified as multipliers "times" conventional to limit the effort dedicated to estimating future conventional vehicle technology changes.
- Projected fuel price – diesel, ethanol, and CNG, and others as specified by the user. (Ref. 3);
- Incremental cost of new technology over time
- Discount rate; and
- Payback period.

In the HVMP model, the truck classes are segmented according to refueling location (i.e. central or multiple locations). The data analysis revealed that all vehicle segments have central refueling

occurring at least 40% of the time. As vehicles age, central refueling declines. This may be explained by the transition from larger fleet operations to small independent owner operators as centrally refueled vehicles age.

Eleven travel distance categories for medium trucks and 21 for heavy trucks are represented in the model. These categories were determined using travel distributions developed with the VIUS data by ORNL (Ref. 5).

Figure 2 and Figure 3 show the distribution for Centrally and Noncentrally refueled vehicles. Type 3 vehicles display the greatest amount of annual travel of all heavy-vehicle classes. Centrally refueled vehicles travel less per year than non-centrally refueled vehicles. In the noncentrally 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. The technology performance assumptions and truck utilization patterns are used to determine payback performance for the advanced technologies in each type and class of vehicle. The model then calculates composite market penetrations and fuel economy values.

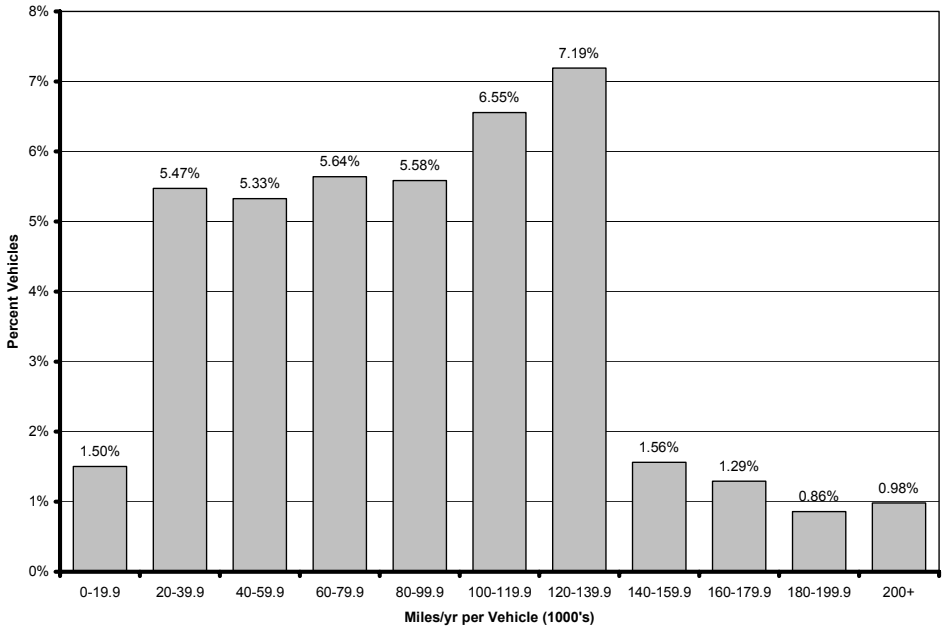

Figure 2. Type 3 Heavy-Vehicle Travel Distribution – Central Refueling

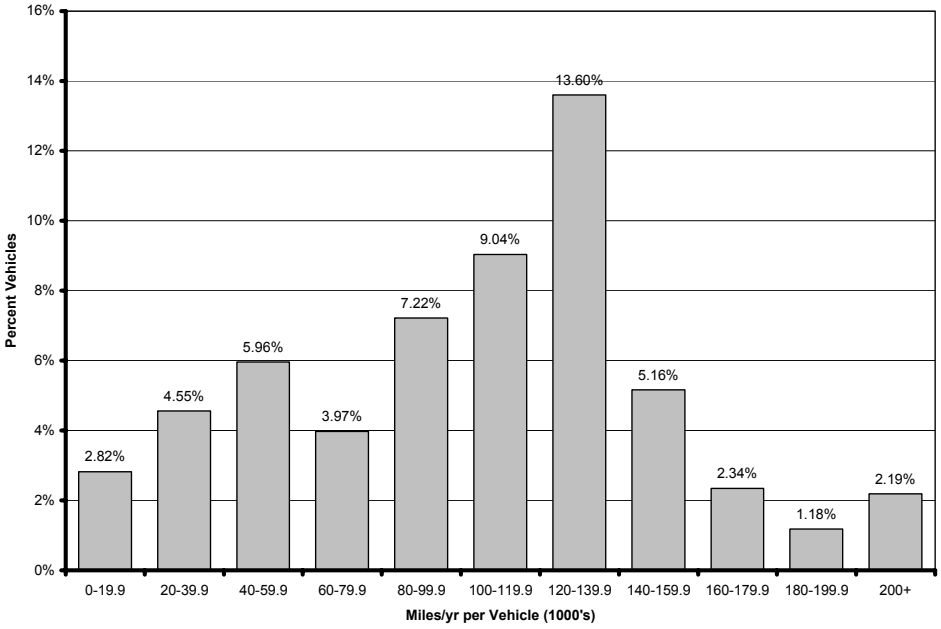

Figure 3. Type 3 Heavy-Vehicle Travel Distribution – Non-Central Refueling

IMPACTT Heavy Truck

This model is a version of the IMPACTT tools developed by M. Mintz of ANL (Ref. 6). Fuel economies and market penetrations determined in HVMP are inputs to this model, which determines initial energy savings due to the expected market penetration of the advanced technologies in Medium and Heavy Vehicles. The model also has the capability of estimating criteria emissions savings, and carbon reduction. In addition, it projects the portions of the Medium- and Heavy-Vehicle *fleet* that are advanced technologies.

Heavy Truck Summary

This report generator provides nine tables of the first-order benefits for the period covering 2000 through 2030.

Specific results are generated for the following:

- Class 3 – 8 Energy and Emissions Reductions
- Technology Market Penetrations
- Sales and Stocks of Advanced Technology Vehicles
- Heavy Vehicle Energy Use, including a breakdown by Class and Technology
- CO_2 Emissions and Emissions Reduction
- NOx, CO, and Non-methane Hydrocarbon Emissions and Emission Reductions, and
- Value of Emissions Reductions (both Carbon and Criteria Pollutants)

Results

Principal results for QM04 analysis are provided in **Tables 8 through 14**. These are reproduced from the Heavy Truck Summary Model.

Table 8. Summary Class 3-8 Energy and Emission Reductions

	Energy Reduction			Alternative	Petroleum	Carbon Reduction			Energy Cost Savings			Incremental
	Total	Class 3-6	Class 7-8	Fuel Use	Reduction	Total	Class 3-6	Class 7-8	Total	Class 3-6	Class 7-8	Vehicle Cost
Year	mmb/d	mmb/d	mmb/d	mmb/d	mmb/d	(MMTCe)	(MMTCe)	(MMTCe)	million 2000$	million 2000$	million 2000$	million 2000$
2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
2010	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	1.14	1.23	-0.10	13.14
2011	0.000	0.000	0.000	0.000	0.000	0.021	0.013	0.008	10.52	6.46	4.06	42.73
2012	0.002	0.001	0.001	0.000	0.002	0.070	0.028	0.042	35.52	14.18	21.33	75.50
2013	0.004	0.001	0.003	0.000	0.004	0.180	0.052	0.128	91.55	26.63	64.92	127.70
2014	0.010	0.002	0.007	0.000	0.010	0.416	0.105	0.311	209.79	53.01	156.79	230.34
2015	0.020	0.004	0.016	0.000	0.020	0.853	0.179	0.674	431.76	90.63	341.13	354.41
2016	0.038	0.007	0.030	0.000	0.038	1.597	0.315	1.282	805.32	158.70	646.62	527.18
2017	0.063	0.011	0.051	0.000	0.063	2.649	0.485	2.164	1,330.69	243.72	1,086.97	643.21
2018	0.097	0.016	0.081	0.000	0.097	4.085	0.668	3.417	2,053.30	335.81	1,717.49	752.84
2019	0.138	0.020	0.118	0.000	0.138	5.839	0.846	4.993	2,919.44	423.09	2,496.35	864.82
2020	0.193	0.027	0.166	0.000	0.193	8.143	1.136	7.007	4,074.73	568.65	3,506.07	1,066.09
2021	0.257	0.036	0.221	0.000	0.257	10.857	1.507	9.350	5,502.57	763.93	4,738.65	1,129.32
2022	0.328	0.046	0.283	0.000	0.328	13.861	1.923	11.938	7,113.88	986.76	6,127.12	1,184.78
2023	0.405	0.057	0.348	0.000	0.405	17.113	2.411	14.702	8,893.18	1,252.89	7,640.29	1,253.68
2024	0.491	0.071	0.420	0.000	0.491	20.741	3.017	17.724	10,911.68	1,587.13	9,324.55	1,380.44
2025	0.588	0.090	0.498	0.000	0.588	24.814	3.793	21.021	13,213.77	2,019.76	11,194.01	1,546.22
Cumulative Total From Year 2000 to Year												
2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	(0.00)	-	0.00
2010	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	1.14	1.23	(0.10)	13.14
2015	0.037	0.009	0.028	0.000	0.037	1.542	0.380	1.163	780.28	192.14	588.14	843.83
2020	0.565	0.091	0.474	0.000	0.565	23.855	3.830	20.025	11,963.77	1,922.12	10,041.65	4,697.97

Table 9. Market Penetration of Advanced Technologies in Heavy Vehicles

	Class 7-8 Type 1		Class 7-8 Type 2		Class 7-8 Type 3		CLASS 7-8 Final		CLASS 3-6 Final	
Year	CURRENT	ENHANCED	CURRENT	ENHANCED	CURRENT	ENHANCED	CURRENT	ENHANCED	CURRENT	ENHANCED
2000										
2001	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2002	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2003	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2004	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2005	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2006	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2007	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2008	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2009	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2010	0.0%	0.0%	0.0%	0.0%	1.5%	0.0%	0.9%	0.0%	1.0%	0.0%
2011	0.0%	0.0%	0.1%	0.0%	4.1%	0.0%	2.5%	0.0%	3.7%	0.0%
2012	0.0%	0.0%	0.3%	0.0%	8.7%	0.0%	5.2%	0.0%	5.1%	0.0%
2013	0.1%	0.0%	1.1%	0.0%	14.7%	0.0%	9.0%	0.0%	8.0%	0.0%
2014	0.6%	0.0%	3.9%	0.0%	23.6%	0.0%	15.0%	0.0%	16.0%	0.0%
2015	1.2%	0.0%	7.1%	0.0%	38.3%	0.0%	24.7%	0.0%	21.6%	0.0%
2016	2.7%	0.0%	13.9%	0.0%	50.2%	0.0%	33.6%	0.0%	35.8%	0.0%
2017	5.1%	0.0%	24.9%	0.0%	59.0%	0.0%	41.7%	0.0%	42.5%	0.0%
2018	11.5%	0.0%	39.0%	0.0%	68.4%	0.0%	51.6%	0.0%	43.2%	0.0%
2019	18.6%	0.0%	47.9%	0.0%	73.8%	0.0%	58.1%	0.0%	48.0%	0.0%
2020	26.1%	0.0%	59.0%	0.0%	83.2%	0.0%	67.6%	0.0%	59.9%	0.0%
2025	58.8%	0.0%	83.3%	0.0%	93.8%	0.0%	85.2%	0.0%	91.2%	0.0%
2030	77.9%	0.0%	91.1%	0.0%	97.3%	0.0%	92.5%	0.0%	91.5%	0.0%

Table 10. Heavy-Vehicle (Class 3-8) Sales and Stocks of Advanced Technology Vehicles

	SALES				STOCKS				STOCKS (Percent of Total)			
	3-6		7&8		3-6		7&8		3-6		7&8	
Year	Current	Enhanced	Current	Enhanced	Current	Enhanced	Current	Enhanced	Current	Enhanced	Current	Enhanced
2000	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2001	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2002	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2003	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2004	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2005	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2006	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2007	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2008	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2009	0	0	0	0	0	0	0	0	0.0%	0.0%	0.0%	0.0%
2010	2,821	0	3,725	0	2,821	0	3,725	0	0.1%	0.0%	0.1%	0.0%
2011	10,609	0	10,688	0	13,421	0	14,401	0	0.3%	0.0%	0.2%	0.0%
2012	14,657	0	22,934	0	28,032	0	37,284	0	0.6%	0.0%	0.6%	0.0%
2013	23,349	0	40,199	0	51,267	0	77,338	0	1.0%	0.0%	1.2%	0.0%
2014	47,315	0	67,318	0	98,343	0	144,317	0	1.9%	0.0%	2.2%	0.0%
2015	64,660	0	111,599	0	162,509	0	255,213	0	3.1%	0.0%	3.8%	0.0%
2016	108,777	0	153,433	0	270,370	0	407,262	0	5.1%	0.0%	5.9%	0.0%
2017	129,299	0	190,497	0	398,018	0	595,210	0	7.4%	0.0%	8.4%	0.0%
2018	133,944	0	240,073	0	529,215	0	830,921	0	9.7%	0.0%	11.5%	0.0%
2019	152,862	0	276,645	0	677,804	0	1,100,473	0	12.1%	0.0%	14.9%	0.0%
2020	197,122	0	332,267	0	868,535	0	1,421,754	0	15.2%	0.0%	18.8%	0.0%
2021	202,378	0	358,164	0	1,061,598	0	1,763,439	0	18.4%	0.0%	23.0%	0.0%
2022	209,864	0	377,989	0	1,258,363	0	2,117,606	0	21.5%	0.0%	27.1%	0.0%
2023	230,553	0	391,394	0	1,471,058	0	2,475,994	0	24.8%	0.0%	31.1%	0.0%
2024	267,897	0	416,901	0	1,715,244	0	2,848,655	0	28.6%	0.0%	35.1%	0.0%
2025	321,741	0	445,358	0	2,006,235	0	3,236,253	0	33.1%	0.0%	39.2%	0.0%
2030	344,643	0	512,589	0	3,384,521	0	5,114,148	0	52.1%	0.0%	56.4%	0.0%

Table 11. Heavy-Vehicle (Class 3-8) Energy Use

Table A-37 Heavy Vehicle (Class 3-8) Energy Use

Year	Base Case Energy Use, Trillion BTUs			Class 3-6 Technology Energy Use, Trillion BTUs			Class 7&8 DOE Program Energy Use, Trillion BTUs	Class 3-8 Current & Enhanced Energy Use	Energy Savings	Energy Savings by Program, Trillion BTUs	
	Class 3-6	Class 7-8	Total	Class 3-6 Conv.	DOE Program	Total	DOE Program	Trillion BTUs	Trillion BTUs	Current Program	Enhanced Program
2000											
2001	839.1	3,815.6	4,654.7	839.1	0.0	839.1	3,815.6	4,654.7	0.0	0.0	0.0
2002	844.9	3,945.3	4,790.2	844.9	0.0	844.9	3,945.3	4,790.2	0.0	0.0	0.0
2003	861.4	4,071.7	4,933.1	861.4	0.0	861.4	4,071.7	4,933.1	0.0	0.0	0.0
2004	872.1	4,152.6	5,024.7	872.1	0.0	872.1	4,152.6	5,024.7	0.0	0.0	0.0
2005	883.9	4,192.1	5,076.0	883.9	0.0	883.9	4,192.1	5,076.0	0.0	0.0	0.0
2006	886.9	4,199.9	5,086.8	886.9	0.0	886.9	4,199.9	5,086.8	0.0	0.0	0.0
2007	895.5	4,233.0	5,128.4	895.5	0.0	895.5	4,233.0	5,128.4	0.0	0.0	0.0
2008	910.0	4,275.0	5,185.1	910.0	0.0	910.0	4,275.0	5,185.1	0.0	0.0	0.0
2009	927.5	4,342.0	5,269.5	927.5	0.0	927.5	4,342.0	5,269.5	0.0	0.0	0.0
2010	947.8	4,420.1	5,367.9	946.7	1.0	947.7	4,420.1	5,367.7	0.1	0.1	0.0
2011	971.7	4,519.7	5,491.4	966.6	4.5	971.0	4,519.3	5,490.4	1.0	1.0	0.0
2012	991.8	4,604.0	5,595.8	981.4	9.0	990.4	4,601.9	5,592.3	3.5	3.5	0.0
2013	1,008.0	4,696.7	5,704.6	989.5	15.9	1,005.3	4,690.3	5,695.6	9.0	9.0	0.0
2014	1,024.1	4,789.8	5,813.9	989.3	29.5	1,018.8	4,774.2	5,793.0	20.8	20.8	0.0
2015	1,041.4	4,888.4	5,929.8	985.0	47.5	1,032.4	4,854.6	5,887.0	42.8	42.8	0.0
2016	1,059.5	4,989.1	6,048.6	966.9	76.8	1,043.7	4,924.8	5,968.6	80.1	80.1	0.0
2017	1,079.9	5,098.6	6,178.5	945.1	110.5	1,055.6	4,990.2	6,045.8	132.8	132.8	0.0
2018	1,101.1	5,210.5	6,311.6	923.6	144.0	1,067.6	5,039.2	6,106.8	204.7	204.7	0.0
2019	1,122.5	5,317.3	6,439.8	897.6	182.5	1,080.1	5,067.0	6,147.2	292.7	292.7	0.0
2020	1,137.9	5,411.0	6,549.0	854.4	226.6	1,081.0	5,059.9	6,140.8	408.1	408.1	0.0
2021	1,184.8	5,542.4	6,727.2	834.5	274.7	1,109.2	5,073.8	6,183.0	544.2	544.2	0.0
2022	1,233.4	5,677.9	6,911.3	814.1	322.9	1,137.0	5,079.5	6,216.5	694.7	694.7	0.0
2023	1,284.3	5,816.7	7,100.9	789.3	374.1	1,163.4	5,079.8	6,243.2	857.7	857.7	0.0
2024	1,337.3	5,959.6	7,296.9	754.0	432.0	1,186.1	5,071.2	6,257.3	1039.6	1,039.6	0.0
2025	1,392.4	6,103.5	7,495.9	701.7	500.6	1,202.3	5,049.9	6,252.2	1243.7	1,243.7	0.0
2026	1,419.5	6,223.0	7,642.6	637.1	556.5	1,193.5	5,002.4	6,195.9	1446.7	1,446.7	0.0
2027	1,447.4	6,344.9	7,792.3	577.0	608.5	1,185.5	4,957.9	6,143.4	1648.9	1,648.9	0.0
2028	1,475.6	6,469.2	7,944.8	521.2	656.8	1,178.1	4,917.1	6,095.2	1849.6	1,849.6	0.0
2029	1,504.6	6,595.9	8,100.5	469.7	701.8	1,171.5	4,877.0	6,048.5	2052.0	2,052.0	0.0
2030	1,534.1	6,725.2	8,259.3	422.4	743.3	1,165.7	4,839.3	6,005.0	2254.3	2,254.3	0.0
Cumulative Total From Year 2000 to Year											
2005	4,301	20,177	24,479	4,301	0	4,301	20,177	24,479	0	0	0
2010	8,869	41,647	50,516	8,868	1	8,869	41,647	50,516	0	0	0
2015	13,906	65,146	79,052	13,780	107	13,887	65,146	78,974	77	77	0
2020	19,407	91,172	110,579	18,367	848	19,215	91,172	109,384	1,196	1,196	0
2025	25,839	120,273	146,111	22,261	2,752	25,013	120,273	140,536	5,576	5,576	0
2030	33,220	152,631	185,851	24,888	6,019	30,907	152,631	171,024	14,827	14,827	0

Table 12. Heavy-Vehicle (Class 3-8) CO2 Emissions and Emission Reductions (1,000 tons)

							OPERATIONAL EMISSIONS Reduction			UPSTREAM EMISSIONS Reduction			TOTAL REDUCTION		
	Base Case			Technology Case											
Year	CLS 3-6	CLS 7&8	Total	CLS 3-6	CLS 7&8	Total	CLS 3-6	CLS 7&8	Total	CLS 3-6	CLS 7&8	Total	CLS 3-6	CLS 7&8	Total
2000	63,975	294,947	358,922	63,975	294,947	358,922	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001	64,529	302,958	367,486	64,529	302,958	367,486	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002	65,113	313,255	378,367	65,113	313,255	378,367	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	66,528	323,294	389,822	66,528	323,294	389,822	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	67,515	329,715	397,230	67,515	329,715	397,230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	68,614	332,853	401,467	68,614	332,853	401,467	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	69,028	333,470	402,498	69,028	333,470	402,498	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2007	69,886	336,097	405,983	69,886	336,097	405,983	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2008	71,127	339,437	410,564	71,127	339,437	410,564	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2009	72,489	344,755	417,244	72,489	344,755	417,244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	74,097	350,953	425,050	74,089	350,954	425,043	8.3	-0.8	7.6	0.0	0.0	0.0	8.3	-0.8	7.6
2011	75,963	358,867	434,830	75,919	358,835	434,754	44.1	31.7	75.8	0.0	0.0	0.0	44.1	31.7	75.8
2012	77,535	365,561	443,096	77,436	365,394	442,830	98.5	167.2	265.7	0.0	0.0	0.0	98.5	167.2	265.7
2013	78,802	372,916	451,717	78,616	372,407	451,023	186.0	508.5	694.5	0.0	0.0	0.0	186.0	508.5	694.5
2014	80,060	380,312	460,372	79,685	379,075	458,759	375.7	1,236.9	1,612.6	0.0	0.0	0.0	375.7	1,236.9	1,612.6
2015	81,417	388,140	469,556	80,773	385,456	466,229	644.0	2,683.5	3,327.5	0.0	0.0	0.0	644.0	2,683.5	3,327.5
2016	82,830	396,136	478,966	81,690	391,033	472,723	1,139.6	5,103.8	6,243.4	0.0	0.0	0.0	1,139.6	5,103.8	6,243.4
2017	84,424	404,831	489,255	82,658	396,220	478,879	1,766.0	8,610.4	10,376.4	0.0	0.0	0.0	1,766.0	8,610.4	10,376.4
2018	86,081	413,713	499,794	83,639	400,116	483,754	2,441.9	13,597.6	16,039.6	0.0	0.0	0.0	2,441.9	13,597.6	16,039.6
2019	87,757	422,195	509,952	84,664	402,324	486,988	3,093.1	19,871.0	22,964.1	0.0	0.0	0.0	3,093.1	19,871.0	22,964.1
2020	88,963	429,636	518,600	84,787	401,753	486,540	4,176.2	27,883.8	32,060.0	0.0	0.0	0.0	4,176.2	27,883.8	32,060.0
2021	92,623	440,070	532,692	87,052	402,861	489,913	5,570.8	37,208.7	42,779.5	0.0	0.0	0.0	5,570.8	37,208.7	42,779.5
2022	96,423	450,825	547,247	89,284	403,316	492,599	7,139.2	47,509.1	54,648.3	0.0	0.0	0.0	7,139.2	47,509.1	54,648.3
2023	100,402	461,844	562,245	91,411	403,334	494,745	8,990.2	58,509.7	67,499.9	0.0	0.0	0.0	8,990.2	58,509.7	67,499.9
2024	104,548	473,192	577,740	93,254	402,656	495,910	11,293.6	70,535.9	81,829.5	0.0	0.0	0.0	11,293.6	70,535.9	81,829.5
2025	108,854	484,620	593,474	94,603	400,964	495,567	14,250.8	83,655.9	97,906.7	0.0	0.0	0.0	14,250.8	83,655.9	97,906.7
2030	119,933	533,983	653,916	92,044	384,240	476,285	27,888.5	149,743.1	177,631.7	0.0	0.0	0.0	27,888.5	149,743.1	177,631.7
Cumulative Total From Year 2000 to Year															
2005							0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010							8.3	-0.8	7.6	0.0	0.0	0.0	8.3	-0.8	7.6
2015							1,356.6	4,626.9	5,983.5	0.0	0.0	0.0	1,356.6	4,626.9	5,983.5
2020							13,973.4	79,693.6	93,667.0	0.0	0.0	0.0	13,973.4	79,693.6	93,667.0
2025							61,218.0	377,112.8	438,330.8	0.0	0.0	0.0	61,218.0	377,112.8	438,330.8
2030							174,330.3	999,798.3	1,174,128.6	0.0	0.0	0.0	174,330.3	999,798.3	1,174,128.6

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Appendix

Overview of Heavy Vehicle Market Penetration Model (HVMP)

The HVMP is a spreadsheet model that currently operates in Excel (Office 2000 and associated versions). It consists of nine spreadsheets linked to other models. It is operated by the user specifying inputs and then initiating macros that perform iterative calculations to determine market shares by technology in percents of new vehicle sales. The name and a brief description of each page in the workbook are provided below:

1. **Inputs**—user specifies incremental technology cost and relative fuel efficiency for current and advanced technology(ies). These inputs are specified by year to 2035 and separately for Class 7 and 8 and Classes 3 through 6 vehicles.
2. **Fuel Prices**—array of fuel price information. Typically linked to other AEO-source files.
3. **Market Data (6 pages)**—Distribution of vehicle-use patterns from 1997 VIUS
4. **Type 1 (7 pages)**—Contains macro in which calculations are performed to determine market distribution of conventional and new technologies for "Type 1" Class 7 and 8 vehicles. Calculations are performed separately for centrally refueled and noncentrally refueled vehicles.
5. **Type 2 (6 pages)**—Contains macro in which calculations are performed to determine market distribution of conventional and new technologies for "Type 2" Class 7 and 8 vehicles. Calculations are performed separately for centrally refueled and noncentrally refueled vehicles.
6. **Type 3 (6 pages)**—Contains macro in which calculations are performed to determine market distribution of conventional and new technologies for "Type 3" Class 7 and 8 vehicles. Calculations are performed separately for centrally refueled and noncentrally refueled vehicles.
7. **Med (6 pages)**—Contains macro in which calculations are performed to determine market distribution of conventional and new technologies for "Medium", i.e., Class 3 through 6 vehicles. Calculations are performed separately for centrally refueled and noncentrally refueled vehicles.
8. **New MPG (2 pages)**—Shows the effect of new technology penetrations on the fleet fuel economy by vehicle class.
9. **Market Penetration (1 page)**—Summarizes the market penetration of new technologies in units of new vehicle sales percentage. Lists market shares for each Class 7 and 8 vehicle type, Class 7 and 8 composite, and Classes 3 through 6 (composite).

Table A-1. Heavy-Vehicle Market-Penetration Model Calculation Methodology

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