APPENDIX F – FREEDOMCAR AND VEHICLE TECHNOLOGIES PROGRAM INPUTS FOR FY 2008 BENEFITS ESTIMATES

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Program Summary

The FreedomCAR and Vehicle Technologies (FCVT) Program provides technology-focused research and development activities for: 1) improving the energy efficiency of current cars, light trucks, and heavy vehicles; and 2) developing technologies that will transition vehicle technology away from petroleum fuels. These activities could result in significant benefits over the next 30 years as more hybrid-electric vehicles, lightweight materials, low-temperature combustion regimes, and alternative fuels (including hydrogen) are used.

FCVT technology is aimed at light vehicles and heavy vehicles. Light vehicles include cars and light trucks (pickups, SUVs, minivans, and vans). Heavy vehicles include medium and heavy trucks and buses.

DOE works with its industry partners through two partnerships: the FreedomCAR and Fuel Partnership, and the 21st Century Truck Partnership. These two partnerships are described at these Web sites:
http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/freedomcar/index.html
http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/21centurytruck/index.html

The FreedomCAR and Fuel Partnership (the Partnership) began in September 2003 as an expansion of the FreedomCAR Partnership, which was originally established in January 2002. The Partnership was established by Secretary of Energy Spencer Abraham and senior executives of DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation. The CAR in FreedomCAR stands for Cooperative Automotive Research.

The Partnership is an effort to examine and advance the precompetitive, high-risk research needed to develop the component and infrastructure technologies necessary to enable a full range of affordable cars and light trucks, and the fueling infrastructure for them that will reduce the dependence of the Nation’s personal transportation system on imported oil and minimize harmful vehicle emissions, without sacrificing freedom of mobility and freedom of vehicle choice.

The 21st Century Truck Partnership is an industry-government collaboration among heavy-duty engine manufacturers, heavy-duty truck and bus manufacturers, heavy hybrid powertrain manufacturers, and four Federal Government agencies. The partners work cooperatively to develop a balanced portfolio of research aimed at achieving their research goals, coordinating their research activities as appropriate, and making effective use of the Nation's research universities and national laboratories. Proprietary research agreements between individual companies and Federal agencies, which cannot be shared with industrial competitors, will continue to be funded appropriately. By sharing information across four Federal agencies and 16 private companies, research can be focused on selected projects that show the greatest likelihood of near-term success and fleet-wide effectiveness.

This appendix is divided into a Light Vehicles section and a Heavy Vehicles section.

Light Vehicles

Significant Changes from Previous Analysis

One of the new technologies specifically called out by the president in his 2006 State of the Union Address is the development of plug-in hybrid electric vehicles (PHEVs). PHEVs can draw some of their energy from the electric grid, thus further reducing oil use (as compared to the potential reduction from current HEVs) when electricity is produced from sources other than petroleum. Higher energy capacity batteries could provide an electric range for these vehicles of up to 40 miles daily (covering the commuting distance of many Americans). The battery energy could be restored by connecting to an electric outlet. Initiated in FY 2007, this promising research will be expanded in FY 2008 (under FCVT's Hybrid Electric Systems Subprogram) and in subsequent years. The FCVT Program expects to have the PHEV technology validated by 2014.

The Baseline ("without DOE RD3" case)

For light vehicles, it is assumed for the baseline that HEVs would continue to increase their market share over time, but that their fuel economy would not improve over what the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) projects, because AEO assumptions were consistent with FCVT's technical judgment. It is assumed that PHEVs would not enter the market at all in the baseline, because the barriers (such as the performance and costs of batteries and fast chargers) are very high, and industry has shown no willingness to overcome them without Federal support.

Target Market Description

The light-vehicle market 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. The stock of cars and light trucks is about 230 million vehicles. EIA projects both sales and stock to grow to more than 21 million and 330 million respectively by 2030. Most vehicles are driven less than 250 miles per week. Most light vehicles use gasoline. The average light vehicle lasts about 16 years before being scrapped (Davis 2006, p. 3-13 and 3-15). Light-vehicle fuel economy has remained fairly flat during the past 15 years (Davis 2006, p. 4-7). The FCVT R&D portfolio aims at achieving significant improvements in their energy efficiency. In addition, FCVT focuses on reducing the cost of, and overcoming technical barriers to, volume manufacturing of advanced technology vehicles.

Baseline Adjustments to the AEO2006 Reference Case

The HEV market penetration for 2030 was increased as explained below.

Representation of Program-Relevant Technologies in the AEO Reference Case

All the light-vehicle technologies are represented in the AEO, except for PHEVs. PHEVs were added to the EERE version of the National Energy Modeling System (NEMS). EIA (Maples, Transportation Working Group Meeting, September 29, 2006) indicated that future AEOs will include PHEVs. As assumed by EIA, the FCVT program expects that the performance of light vehicles, as represented by acceleration time to 60 mph, will continue to increase over time.

Removing Effects of Program Activities

There are none of these.

Other Program-Relevant Adjustments to AEO Reference Case

Based on an internal EERE analysis and the increasing sales of current HEVs, the AEO's HEV 2030 market penetration (9.5% for cars and 8.6% for light trucks) was increased to 21% for cars and to 19% for light trucks in the EERE NEMS model. This is a 120% increase in the share for both cars and light trucks. The miles per gallon (mpg) values for HEVs assumed by EIA were used for these vehicles.

The Paumanok Estimates for worldwide HEV production has HEVs growing from 0.3 million in 2006 to 8 million in 2015 (http://www.ttiinc.com/object/me_zogbi_20060710.html). This indicates 2015 production of HEVs being 26 times the 2006 value. If translated to U.S. sales of HEVs, this would mean about 5.7 million HEVs sold in 2015. This is quite a bit higher than the 2006 AEO projection of about 1.2 million HEV sales in 2015. We estimated a much smaller increase in the EIA reference case – 120% more HEVs – for the GPRA reference case.

Program Outputs

The program outputs are shown in the logic diagram below as **Exhibit F-1**. This same logic chain applies to the Heavy Vehicle activity. The actual numerical benefits are shown in other parts of this documentation.

Exhibit F-1. Summary Program Logic Model for FCVT

Inputs	FY06 Activities	Planned Multi-year Outputs	Expected Outcomes
Funding: $173.7M FY04 $156.7M FY05 $166.2M FY06 $166.0M FY07 $151.5M FY08 $151.5M each year through 2020	Vehicle Systems (Heavy Vehicle Systems R&D Activity) and Materials Technologies (Light Weight Materials Technology Activity): Reduce parasitc energy loss to 24% of total engine output and reduce unloaded tractor trailer weight by 21,500 lbs	Vehicle Systems (Heavy Vehicle Systems and Materials Technologies - 24% heavy truck parasitic losses by 2006 -18,000 lb tractor trailer by 2010	Annual Benefits Energy Saving Expense Carbon Emission Reductions Oil Consumption Savings
	Hybrid and Electric Propulsion (Energy Storage Activity): Reduce high power, 25kW, light vehicle, lithum ion battery cost to $750 per battery system	Hybrid and Electric Propulsion - $500 25kW battery by 2010 - High energy 2014 PHEV battery cost of $500/kWh	
	Advanced Combustion Engine R&D (Combustion & Emission Control and Heavy Truck Engine activities) and Fuels Technology: Light vehicle combustion engines will reach 41% brake thermal efficiency and heavy vehicle combustion engines will reach 50% efficiency while meeting EPA 2010 emissions standards (0.2 grNOx/hp	Advanced Combustion Engine R&D - 45% engine efficiency for light duty apps by 2010 - 55% engine efficiency for heavy duty apps by 2012	
	Materials Technology (Lightweight Materials Technology activity): Complete R&D on technologies, which, if implemented in high volume, could reduce the price of automotive carbon fiber to less than $3.00/lb (modeled)	Materials Technology (Lightweight Materials - Body weight reduced by 50% by 2010	

Assumed Budget Projections

The total FY 2008 budget request is shown in Table F-1. The budget for the Heavy Vehicle activity is included in that total. The over-target funding is necessary to meet the program targets.

Table F-1. Funding by Strategic and Program Goal[a]

(dollars in thousands)

	FY 2006 Current Appropriation	FY 2007 Request	FY 2007 House Mark	FY 2007 Senate Mark	FY 2008 Request	Over Target Increment
Vehicle Technologies						
Hybrid Electric Systems	0	0	0	0	70,742	*+9,922*
Vehicle Systems	13,056	13,315	13,315	13,315	0	*0*
Hybrid and Electric Propulsion	43,977	50,841	50,841	50,841	0	*0*
Advanced Combustion Engine R&D	41,628	46,706	52,613	46,706	32,000	*+2,550*
Materials Technology	35,269	29,786	29,786	29,786	22,881	*+10,501*
Fuels Technology	13,709	13,845	13,845	13,845	13,845	*0*
Technology Integration	0	0	0	0	8,804	*+4,893*
Innovative Concepts	495	500	500	500	0	*0*
Technology Introduction	6,250	11,031	16,638	15,031	0	*0*
Biennial Peer Reviews	990	0	0	0	0	*0*
Technical/Program Management Support	2,475	0	0	0	0	*0*
Congressionally Directed Activities	24,255	0	0	10,000	0	*0*
Total, Vehicle Technologies	182,104	166,024	177,538	180,024	148,272	*+27,866*

a. The amount of the request is confidential until after the budget submission to Congress.

The out-year budgets through FY 2012 are shown in **Table F-2**. From FY 2013 through FY 2019, the annual budgets are assumed to be comparable to the FY 2012 budget.

Table F-2. Out-Year Funding Profile by Subprogram[a]

	(dollars in thousands)			
	FY 2009	FY 2010	FY 2011	FY 2012
Vehicle Technologies				
Hybrid Electric Systems	70,637	70,585	70,546	70,487
Advanced Combustion Engine R&D	31,819	31,729	31,662	31,561
Materials Technology	22,881	22,881	22,881	22,881
Fuels Technology	13,845	13,845	13,845	13,845
Technology Integration	8,804	8,804	8,804	8,804
Congressionally Directed Activities	0	0	0	0
Total, Vehicle Technologies	147,986	147,844	147,738	147,578

a. The amount of the request is confidential until after the budget submission to Congress.

Description of Key Activities

FCVT has worked with industry to identify the priority areas of research needed to develop advanced vehicle technologies to reduce and eventually eliminate petroleum use. These research areas and associated activities are Vehicle Systems; Hybrid and Electric Propulsion; Advanced Combustion Engines; and Fuels, Materials Technologies, and Technology Introduction.

Vehicle Systems integrates all other research activities and their performance targets to confirm the correct direction and ultimately the success of the FCVT Program. The Vehicle Systems Subprogram is comprised of three key activities: Simulation and Technology Validation, Heavy Vehicle Systems R&D, and Light-Vehicle Systems R&D.

Hybrid and Electric Propulsion focuses on the energy storage, power electronics, and electric machinery required for hybrid drive systems. The Energy Storage activity will reduce the cost of a 25 kW battery from $3,000 (2004 baseline) to $500 by 2010. An integrated inverter/motor subsystem is not currently available on the market; but, if one were produced today, it is estimated that it would cost more than $40/kW. By 2010, the Power Electronics and Electric Machinery Activity will reduce this cost to $12/kW. This technology will support the 2014 PHEV target.

Advanced Combustion Engine R&D and Fuels Technology aims to develop significantly more efficient engines and, eventually, a major reduction in petroleum consumption. Work in this area expands the fundamental knowledge of engine combustion and an understanding of the relationships between mobile emissions, quantifiable health hazards (to preclude introducing unintended human health impacts), and the advanced fuel requirements for these engines to realize their full potential. These subprograms will achieve a light-duty engine efficiency of 45% by 2010 (from 30% in 2002), and a heavy-duty engine efficiency of 55% by 2013 (from ~40% in 2002). The work will also identify fuel formulations by 2010 that will enable the replacement of at least 10% petroleum fuels (currently 3%).

Materials Technologies includes the development of high-strength, lightweight materials for the frame, body, chassis, and powertrain systems for light- and heavy-duty vehicles. The targets are focused on affordability while meeting performance, safety, and reusability objectives. By 2012, material technologies will enable a 50% weight reduction of automobiles (relative to the 1997 baseline) and 22% weight reduction of tractor-trailer combinations (relative to the 2003 baseline). The High Temperature Materials Laboratory at Oak Ridge National Laboratory (ORNL) provides state-of-the-art capabilities for fundamental and applied research to users.

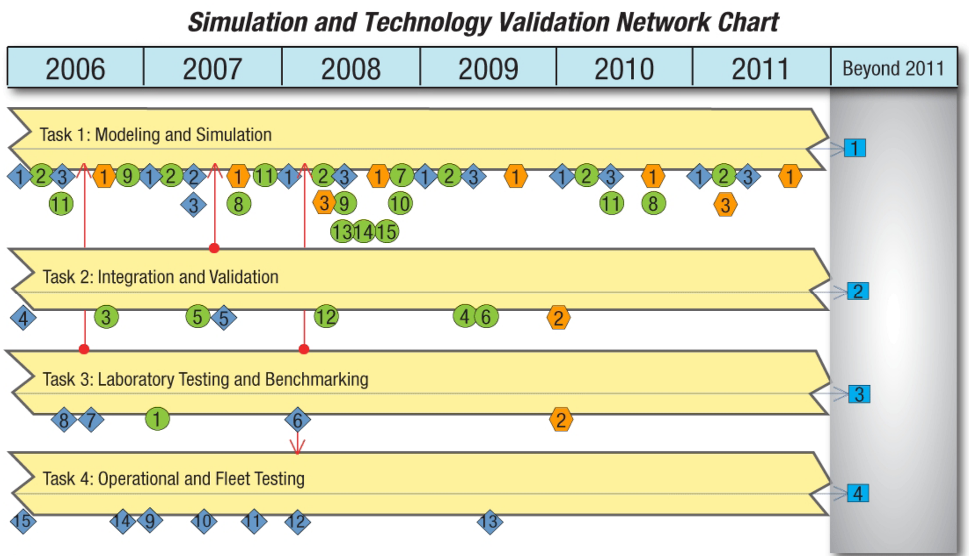
Technology Introduction accelerates the adoption and use of alternative fuels and advanced technology vehicles to help meet national energy and environmental goals. It also contributes to the training of a specialized workforce suitable for the advanced vehicle technologies of the future. As identified in the National Energy Policy (National Energy Policy Development Group, 2001), consumer education and demonstration activities are critical in accelerating the use of advanced energy technologies.

Successful attainment of FCVT goals will provide the pathway for the United States to dramatically change its energy use and petroleum dependence. This will greatly reduce emissions and the transportation sector's contribution to greenhouse gases while sustaining mobility and the freedom of vehicle choice. This vision is necessary for future national energy security and will benefit all.

Milestones and Outputs

The milestones and outputs for the various FCVT light-vehicle activities are shown in **Exhibits F-2 through F-7**.

Exhibit F-2. Simulation and Technology Validation Network Chart



Legend

Milestone

1. Simulation software revision release
2. Complete assessment of dual energy storage technology
3. Program technical targets evaluation and review
4. Completion of MATT system
5. Fuel cell validation
6. Hydrogen fuel cell benchmarking complete
7. Plug-in hybrid evaluation complete
8. MY05 Accord hybrid benchmarking complete
9. Idle reduction demo #1 final cooler report
10. Idle reduction demo #2 final report on road evaluations
11. Idle reduction demo #3 complete analysis and final report
12. Complete on-line installation of idle reduction technologies
13. Hydrogen fuel cell fleet testing complete
14. 2nd Generation Orion hybrid bus testing completed
15. Technical and economic evaluation of APS Hydrogen Fueling Pilot Plant

Supporting Input

1. Hydrogen fuel cell vehicle for benchmarking and fleet testing activities (from industry)
2. Revised program targets from each technology area
3. Fuel cell sub-system for integration and validation (from industry)
4. Integrated motor/inverter to meet FreedomCAR goals from Advanced Power Electronics and Electric Machines
5. Prototype internal PM motor from Advanced Power Electronics and Electric Machines
6. Thermal control system from Advanced Power Electronics and Electric Machines
7. Hybrid body-in-white weight and performance data from Automotive Lightweighting Materials
8. Advanced Competition performance data available for PSAT enhancement
9. Technical data from Waste Heat Recovery
10. Technical results from Combustion and Emissions R&D
11. Technical data from Heavy Truck Engine R&D
12. Validated power electronics cooling technology available
13. 42V battery/ultracapacitor technical information from Energy Storage R&D
14. Hybrid fuel cell battery prototypes and technical results from Energy Storage R&D
15. New candidate battery technical information from Energy Storage R&D

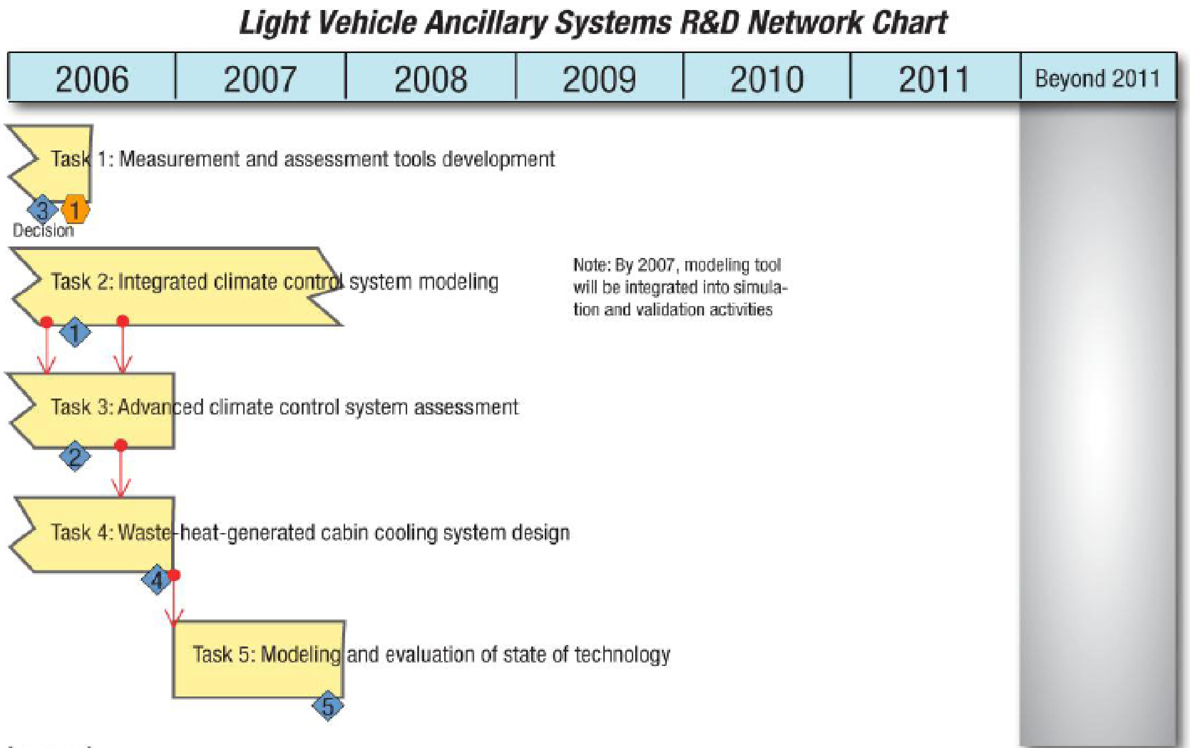
Technology Program Output

1. Revised targets for advanced technology components and subsystems
2. Validated technologies to industry
3. Simulation support to Advanced Competitions

Recurring/On-going

1. Model validation
2. Component validation, contingent on technology availability
3. Advanced vehicle benchmarking, contingent on technology availability
4. Fleet testing and accelerated life testing, contingent on technology availability

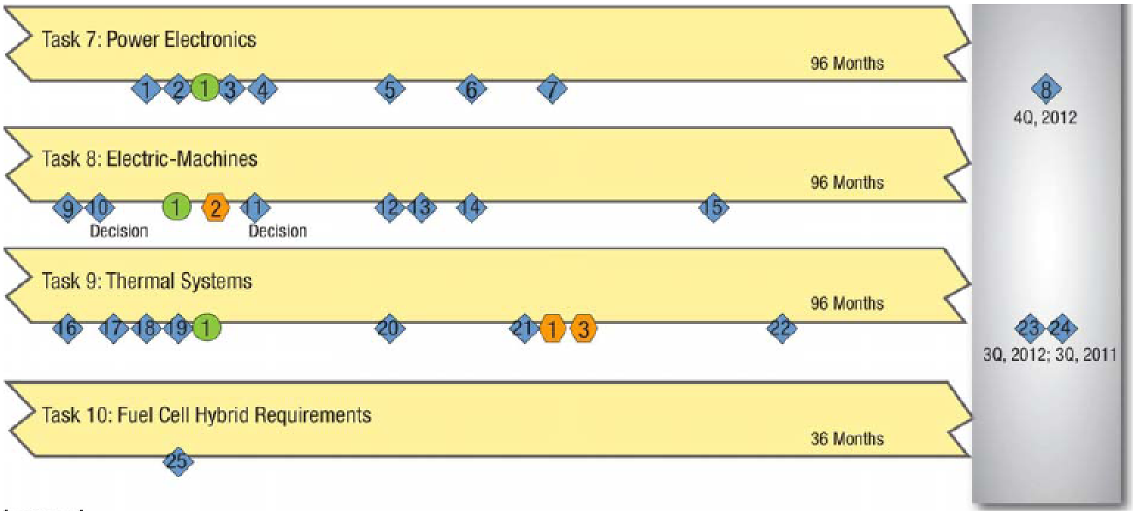
Exhibit F-3. Light-Vehicle Ancillary Systems R&D Network Chart



Legend

Milestone	Milestone	Technology Program Output
1. Validate integrated systems model 2. Available prototype system incorporated into cooling system integrated modeling tool to assess state of development of advanced climate control systems 3. **Decision.** Based on industry feedback, determine future of current thermal comfort tools	4. Feasibility review of waste heat utilization systems 5. Final report evaluating developed hardware, state of technologies and feasible improvements, and impacts on efficiency	1. Thermal comfort tools available (to Heavy Vehicle Systems Optimization)

Exhibit F-3 (continued). Light-Vehicle Ancillary Systems R&D Network Chart



Legend

Milestone

1. Receive Ballard DC/DC converter deliverables for testing and evaluation
2. Hardware delivery of high temperature AIPM
3. Completion of 55kW SiC inverter with high temp packaging
4. Validate improvements in inverter packaging methods with dual inverter
5. Receive high temp, high capacitance improved capacitors for testing and evaluation
6. Completion of cascade inverter build and test, resulting in inverter size reduction to 1/3 of Semikron 2005 inverter
7. Complete build and evaluation of high temperature multilevel converter system with bidirectional DC/DC converter and 50kW inverter
8. Complete build of optimized DC/DC converter for use in FC vehicles
9. Completion of Phase 1 of industrial motor project
10. **Decision.** Verify that developments in field-weakening techniques help attain technical targets for PM motors
11. **Decision.** Validate contribution of developments in magnet materials to technical targets for motors

Milestone

12. Receive Industrial RFP awardee motor for testing and evaluation
13. Complete build and evaluation of high speed (1500rpm) reluctance IPM motor with field enhancement/weakening
14. Complete evaluation of optimized HSUPM motor achieving ½ size reduction of THII Prius
15. Complete build and evaluation HSUPM motor/generator with integrated inverters and thermal cooling system
16. Complete jet impingement modeling tool for single and two phase cooling systems
17. Complete validation testing of floating loop
18. Complete prototype inverter with low resistance IGBT
19. Complete system analysis and specifications for air-cooled inverter/motor
20. Produce first generation of carbon nanotube TIM
21. Complete analysis and modeling of jet impingement with nano-particle enriched fluids
22. Produce first generation of carbon nanotube to replace solder for die connection
23. Complete prototype air cooled system
24. Complete prototype inverter using carbon nano-tube heat spreaders, nano-particle working fluids and carbon nano-tube die joint

Technology Program Output

1. Integrated inverter/motor to meet FreedomCAR goals to Vehicle Systems Analysis
2. Prototype internal PM motor to Vehicle Systems Analysis
3. Thermal-management system to Vehicle Systems Analysis

Supporting Input

1. Fuel cell performance characteristics from HFCIT

Figure 3.2-4. Network Chart for Advanced Power Electronics and Electric Machines

T Multi-Year Program Plan **FINAL DRAFT (8/31/2005)** *3.*

Exhibit F-4. Energy Storage Group Network Chart

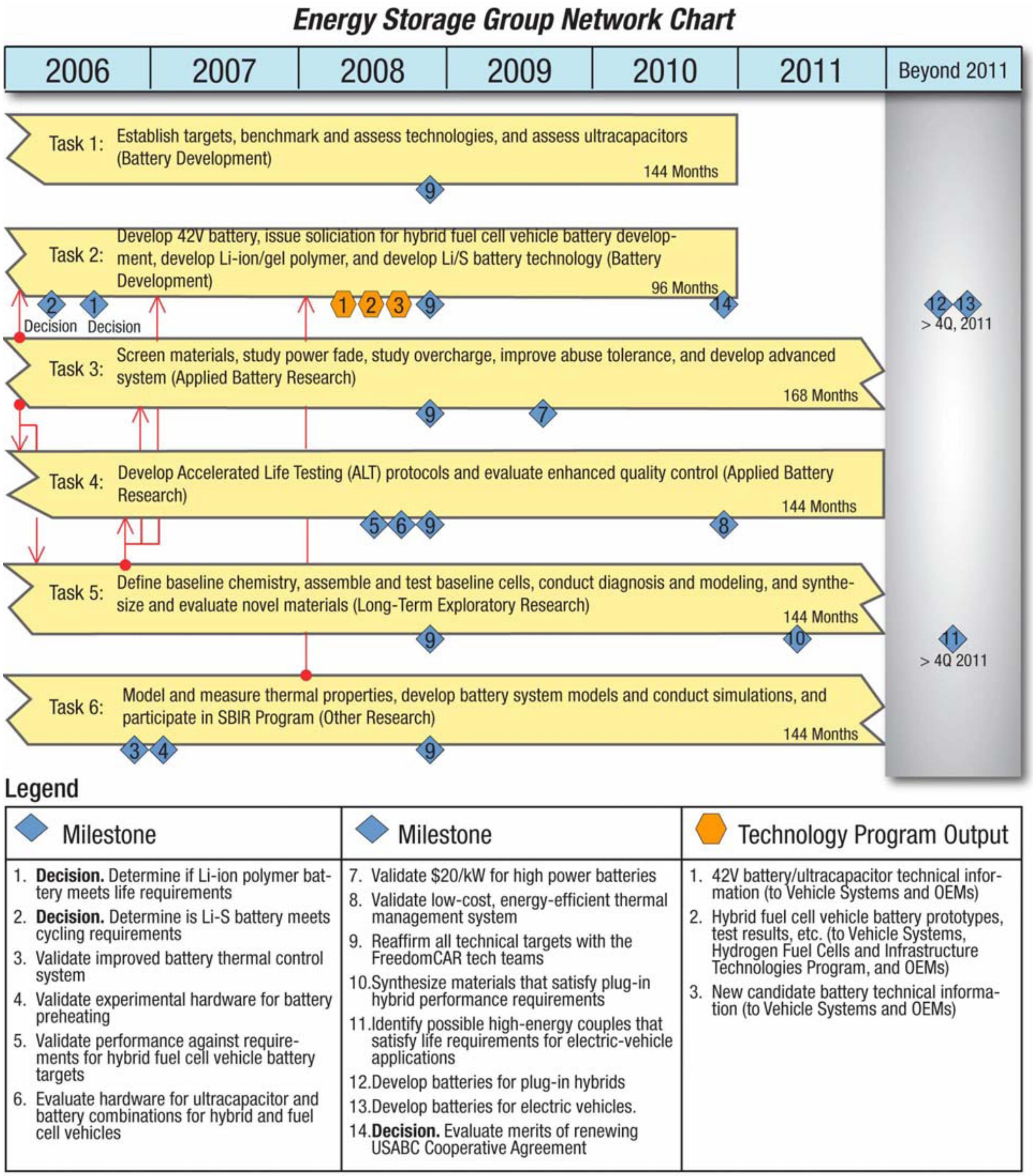
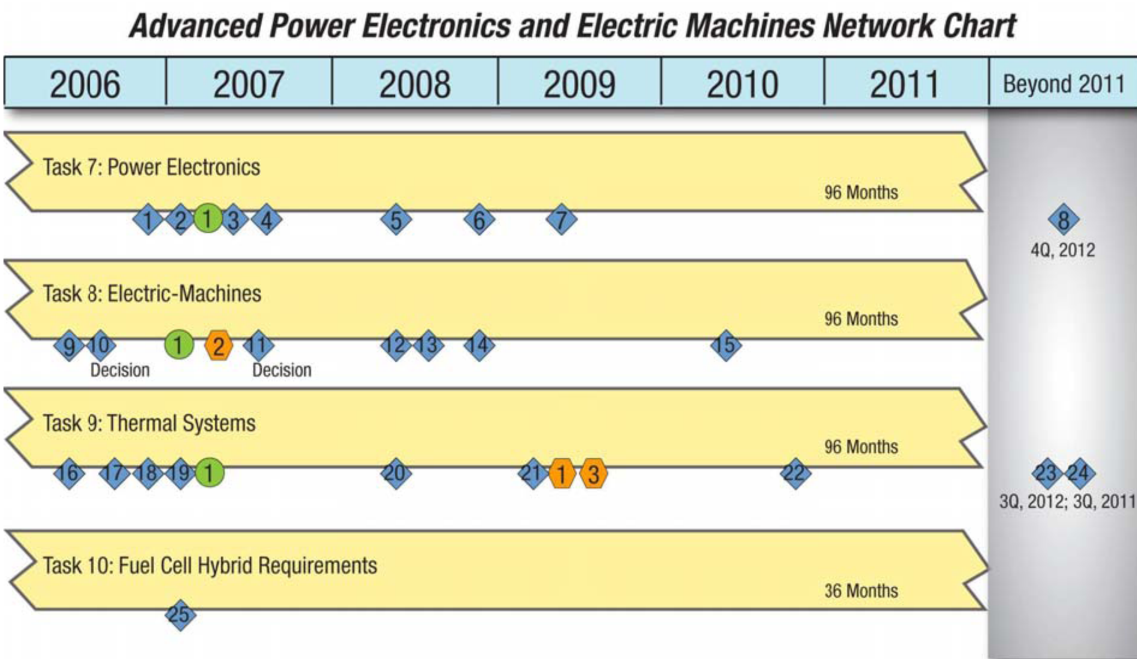


Exhibit F-5. Advanced Power Electronics and Electric Machines Network Chart



Legend

Milestone

1. Receive Ballard DC/DC converter deliverables for testing and evaluation
2. Hardware delivery of high temperature AIPM
3. Completion of 55kW SiC inverter with high temp packaging
4. Validate improvements in inverter packaging methods with dual inverter
5. Receive high temp, high capacitance improved capacitors for testing and evaluation
6. Completion of cascade inverter build and test, resulting in inverter size reduction to 1/3 of Semikron 2005 inverter
7. Complete build and evaluation of high temperature multilevel converter system with bidirectional DC/DC converter and 50kW inverter
8. Complete build of optimized DC/DC converter for use in FC vehicles
9. Completion of Phase 1 of industrial motor project
10. **Decision.** Verify that developments in field-weakening techniques help attain technical targets for PM motors
11. **Decision.** Validate contribution of developments in magnet materials to technical targets for motors

Milestone

12. Receive Industrial RFP awardee motor for testing and evaluation
13. Complete build and evaluation of high speed (1500rpm) reluctance IPM motor with field enhancement/weakening
14. Complete evaluation of optimized HSUPM motor achieving ½ size reduction of THII Prius
15. Complete build and evaluation HSUPM motor/generator with integrated inverters and thermal cooling system
16. Complete jet impingement modeling tool for single and two phase cooling systems
17. Complete validation testing of floating loop
18. Complete prototype inverter with low resistance IGBT
19. Complete system analysis and specifications for air-cooled inverter/motor
20. Produce first generation of carbon nanotube TIM
21. Complete analysis and modeling of jet impingement with nano-particle enriched fluids
22. Produce first generation of carbon nanotube to replace solder for die connection
23. Complete prototype air cooled system
24. Complete prototype inverter using carbon nano-tube heat spreaders, nano-particle working fluids and carbon nano-tube die joint

Technology Program Output

1. Integrated inverter/motor to meet FreedomCAR goals to Vehicle Systems Analysis
2. Prototype internal PM motor to Vehicle Systems Analysis
3. Thermal-management system to Vehicle Systems Analysis

Supporting Input

1. Fuel cell performance characteristics from HFCIT

Exhibit F-6. Automotive Lightweighting Materials Network Chart

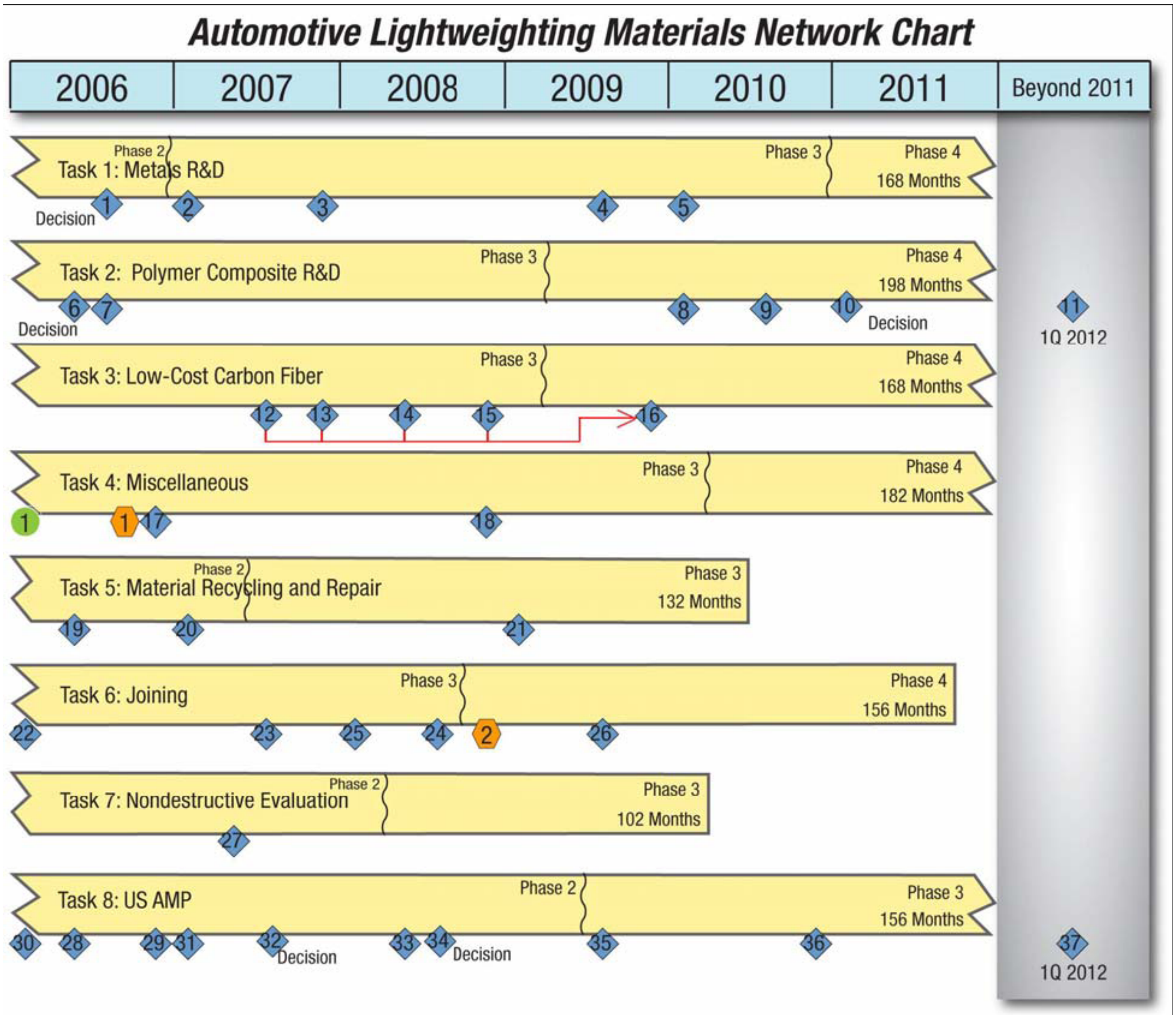


Exhibit F-6 (continued). Automotive Lightweighting Materials Network Chart

Legend

Milestone

1. **Decision.** Complete initial evaluation of nano-reinforced Metal Matrix Composites for automotive applications. Decision point for moving from exploratory research to applied research leading to Milestone 5
2. Complete development of models for prediction of the response of metallic components to deformation during forming and use
3. Develop warm-forming technologies for magnesium sheet
4. Complete evaluation of low-cost magnesium sheet produced by twin-roll casting techniques
5. Complete component demonstration of high ductility nano-reinforced aluminum metal matrix composites for suspension application
6. **Decision.** Define critical technical needs for developing predictive models for thermoplastic composites. Decision point for tasking leading to Milestone 9
7. Complete installation and checkout of the P4C for making Carbon Fiber Preforms
8. Complete development of and demonstrate a low cost carbon fiber structural sheet molding compound
9. Complete development of predictive models for thermoplastics
10. **Decision.** Demonstrate a modified natural fiber reinforced composite with moisture induced strength reduction of no more than 8%
11. Demonstrate hybrid material preforming using carbon and glass fibers simultaneously integrated into a preform
12. Demonstrate satisfactory material properties from lignin based precursors produced as a large tow
13. Demonstrate low cost, non-thermal methods for optomizing carbon fiber precursors
14. Complete installation and check-out of the advanced technology carbon fiber production unit and user's center
15. Demonstrate low-cost, non-thermal methods for stabilizing carbon fiber precursors
16. Validate, via economic analysis, low cost carbon fiber production methods and materials that will yield fiber that costs less than $3.50 per pound

Milestone

17. Develop an understanding of the effect of strain-rate-dependent materials on crash energy absorption capabilities
18. Demonstrate test methods to obtain material parameters that were previously not measurable
19. Complete evaluations of technologies for bulk separation of shredder residue, including electrostatic separation, hydrodynamic floatation, and gravity table separation
20. Demonstrate technology for the removal of substances of concern from recycled automotive materials
21. Complete comprehensive report detailing technology and infrastructure requirements for the recycle of advanced lightweight components and systems for advanced vehicular designs (e.g., hybrids and hydrogen fueled vehicles)
22. Complete evaluation of energy absorption capabilities of prototype bonded and mechanically fastened structures
23. Demonstrate friction stir spot welding techniques for advanced high strength steels
24. Demonstrate welding technologies for application to joining of different product forms of aluminum (e.g., hydroformed tubes to castings)
25. Complete development of predictive models for dimensional control of welded assemblies
26. Demonstrate effective and reliable thermoplastic welding techniques for joining 2 thermoplastic composite parts
27. Demonstrate NDE techniques for real time inspection and control of adhesive bonds and resistance spot welds in aluminum structures at production rates
28. Develop corrosion/wear coatings for completed magnesium components
29. Develop models for processing of powder metals and prediction of performance of PM components
30. Complete Focal project 3 full scale production demonstration of the "B" pillar assembly
31. Complete development of a crash energy management data base to include all work performed under this program

Milestone

32. **Decision.** Complete designs for hybrid materials focal project prototype structure and define critical path forward. Decision point before proceeding to Milestone 34
33. Validate vehicle-level models for energy absorption in crash tests
34. **Decision.** Complete first prototype of hybrid materials focal point structure and identify manufacturing processes. Gate prior to starting work on Milestone 35
35. Complete hybrid material focal project
36. 1st demonstration of high volume hybrid materials technology on a production vehicle
37. Demonstrate integrated modeling and structural analysis of injection molded thermoplastic automotive structure, including crash energy modeling

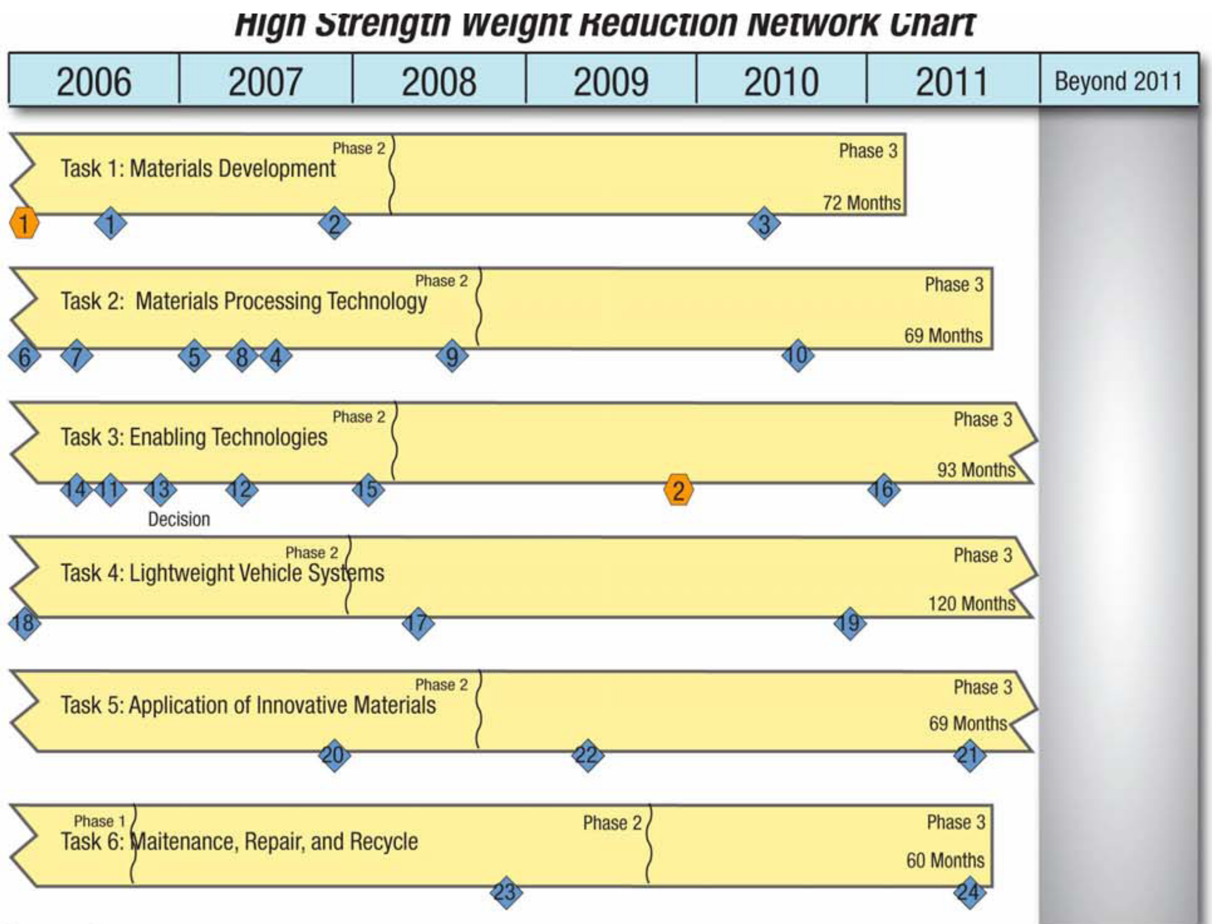
Technology Program Output

1. Validated technologies for production of Carbon Fiber at a cost of $3/lb available to industry
2. Hybrid body-in-white weight and performance data available to Vehicle Systems Analysis

Supporting Input

1. Validated Carbon fiber oxidation technologies provided from the High Strength Weight Reduction Materials technology area

Exhibit F-7. High-Strength Weight Network Chart



Legend

Milestone

1. Evaluate properties of magnesium metal matrix composites produced by various processing routes for application in heavy vehicle suspension components.
2. Evaluate performance of newly developed advanced braking materials in dynamometer tests
3. Evaluate the performance of polymer composite materials exposed to UV, weather extremes, and impact simulating long term road exposures
4. Complete fabrication of low-cost magnesium metal matrix composite component and initiate vehicle testing
5. Scale up processing technologies for production of formable Mg alloy sheet and validate performance on prototype components
6. Demonstrate continuous production of aluminum connecting rod with improved mechanical properties using advanced casting process
7. Evaluate durability of prototype superplastically formed aluminum components with road tests on full-size heavy vehicle
8. Manufacture full size leaf springs for heavy vehicle using low-cost titanium powders and advanced processing techniques
9. Demonstrate cost effective production of full-scale magnesium metal matrix composite components for heavy vehicle applications
10. Evaluate performance of large, thin-wall drivetrain castings produced by advanced castings technologies
11. Validate friction stir processing process models using instrumented process samples and mechanical property test results
12. Demonstrate cost-effective rapid friction stir process foe joining lightweight, high strength materials in different product forms
13. **Decision.** Demonstrate ability of microstructural level simulation model to predict the response of a 1500 series steel during machining of heavy vehicle component
14. Demonstrate newly developed attachment techniques for carbon fiber composite heavy truck cross-members on full-size frame
15. Complete Friction Stir Welding trails on prototype assembly containing a combination of aluminum product forms (casting, extrusion, sheet)
16. Complete design guidelines for joints in hybrid materials structures
17. Complete design for hybrid materials focal project for Class 8 vehicles
18. Complete construction of prototype tanker trailer demonstrating 20% weight reduction
19. Demonstrate acceptable performance of prototype hybrid materials focal project structure with vehicle tests
20. Complete validation tests on polymer composite lateral cross members on full size Class 8 vehicle
21. Complete validation testing of full scale prototype aluminum foam cab component for Class 8 vehicles
22. Evaluate properties of high strength, light weight materials strengthened by nanosize structures
23. Complete lab-scale demonstration of recycling process for metal matrix composites.
24. Complete development of field deployable system for early detection of component degradation to allow for preventive maintenance and begin vehicle testing.

Technology Program Output

1. Validated carbon fiber oxidation technologies provided to the Automotive Lightweighting materials technology areas
2. Composite of dissimiliar joining technologies available to industry

Translating Program Outputs to Market Outcomes

The target market is light vehicles (cars and light trucks). Light vehicles are purchased by buyers who vary from one another with respect to driving patterns, number of miles driven each year, and the need for vehicle attributes such as towing, number of seats, and interior volume. Buyers also differ with respect to their desire for acceleration, safety, range, and fuel economy. Thus, there are many vehicle attributes that compete with fuel economy when buyers choose their new vehicles.

The program outputs are vehicle components with their associated efficiencies and costs. These technology components are then placed into new vehicles produced by the manufacturers. How well these advanced vehicles sell in the marketplace is a function of many variables such as: incremental cost when first introduced (which can be affected by company pricing decisions and government incentives and regulations), which model they're introduced in first, the overall fuel efficiency of the advanced vehicle (taking into account any performance changes in the vehicle), and fuel prices.

Key Factors in Shaping Market Adoption of EERE technologies

As noted above, 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. The average buyer is likely to want a three-year payback: i.e., the incremental vehicle cost of the new vehicle technology should be no higher than the fuel savings achieved in three years of vehicle use. The three-year payback assumption was taken from the 2002 CAFE study by the National Academy of Sciences (Ref 4). In addition, the consumer's actions can be significantly affected by the following non-vehicle attributes:

- Fuel Price
- Fuel Availability.

Also important are manufacturing and policy factors. For example, manufacturers have not shown much interest in producing PHEVs, which is obviously a barrier to market adoption that needs to be overcome. Alternatively, the Department of Transportation increased light-truck CAFE standards slightly for Model Year 2008–2011. This means that technologies that improve the fuel economies of light trucks will be adopted in the baseline case. (http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.43ac99aefa80569eea57529cdba046a0/).

Discussion of Inputs

Alternate Technology Light Vehicle (ATV) Market

The alternate technology light vehicles (ATVs) included in the FCVT Program are: gasoline hybrid vehicles, diesel hybrid vehicles, plug-in hybrid vehicles (PHEVs), advanced diesel, and advanced gasoline vehicles. The market for these technologies includes all cars and light trucks sold for both personal and business use. In the current market, annual new vehicle sales are approximately 17 million. The stock of cars and light trucks is about 230 million vehicles. EIA projects both sales and stock to grow to more than 21 million and 330 million respectively by 2030 (EIA-*AEO2006*). Additional growth is expected post-2030, as explained in **Chapter 2** of EERE GPRA Benefits documentation for the FY 2008 budget request and in the appendix describing the long-term modeling.

Methodology and Calculations

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

ATV Attributes: General

ATV attributes were developed based on the FCVT program goals, discussions with FCVT program managers, Powertrain Systems Analysis Toolkit (PSAT) modeling, payback analysis, and review of past GPRA characterizations (Argonne National Laboratory PSAT; Sharer 2005; Rousseau 2005; Moore 2003; Office of Transportation Technologies 2002). The simulation model PSAT was used to evaluate the fuel economy and performance of light vehicles using various technologies. 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. It is assumed that the incremental price for new light-vehicle technologies will equal that value at which a three-year payback would be achieved. The price estimates are described in further detail below. Other attributes were based on a review of past GPRA characterizations and discussions with FCVT program managers.

Because the NEMS and MARKAL models require different levels of detail, FCVT provided two separate vehicle characterizations. In both cases, most of the ATV attributes were characterized as ratios to the attributes of conventional vehicles. For NEMS, the dollar value of the price increments were provided. The attributes are for new vehicles in the year listed. In **Table F-3,** attributes are provided for all six car classes and six light-truck classes that NEMS uses.

In Table F-4, MARKAL input consists of vehicle prices and fuel economy attributes for two aggregate categories, cars and light trucks. Unlike NEMS, MARKAL does not disaggregate these categories into various classes.

Table F-3. ATV Attributes Input to NEMS
(All units are ratios to the conventional gasoline vehicles of the specific year, except for the incremental prices.)
(Shown in 2004 dollars.)

	2-SEATER					MINI-COMPACT					SUB-COMPACT				
	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030
Advanced Diesel	**2014**	**2019**	**2024**	**2025**	**2030**	**2018**	**2023**	**2028**	**2025**	**2030**	**2012**	**2017**	**2022**	**2025**	**2030**
Incremental Vehicle Price ($)	1577	1249	1124	1120	1164	1554	1152	1068	1104	1086	1290	1028	956	945	981
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.33	1.39	1.40	1.40	1.43	1.38	1.40	1.42	1.40	1.43	1.31	1.36	1.40	1.40	1.43
Diesel Hybrid	**2016**	**2021**	**2026**	**2025**	**2030**	**2020**	**2025**	**2030**	**2025**	**2030**	**2016**	**2021**	**2026**	**2025**	**2030**
Incremental Vehicle Price ($)	2396	1844	1648	1677	1673	2350	1682	1562	1682	1562	2031	1559	1392	1415	1410
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	1.00	1.00	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	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	1.66	1.76	1.77	1.76	1.80	1.76	1.76	1.80	1.76	1.80	1.66	1.76	1.77	1.76	1.80
Gasoline Hybrid	**2013**	**2018**	**2023**	**2025**	**2030**	**2011**	**2016**	**2021**	**2025**	**2030**	**2010**	**2014**	**2019**	**2025**	**2030**
Incremental Vehicle Price ($)	1613	1361	1266	1257	1297	1378	1196	1188	1169	1211	1222	1036	1070	1061	1093
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	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	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	1.37	1.47	1.52	1.52	1.55	1.33	1.43	1.52	1.52	1.55	1.31	1.39	1.50	1.52	1.55

Table F-3 (continued)

	2-SEATER					MINI-COMPACT					SUB-COMPACT				
	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030
Plug-in HEV 40	**2024**	**2029**	**2034**	**2025**	**2030**	**2024**	**2029**	**2034**	**2025**	**2030**	**2024**	**2029**	**2034**	**2025**	**2030**
Incremental Vehicle Price ($)	2900	2128	1938	2733	1938	2667	1966	1791	2515	1791	2384	1747	1591	2246	1591
Range	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.05	1.04		1.05	1.03	1.05	1.04		1.05	1.04	1.05	1.04		1.05	1.04
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
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
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
Fuel Economy	1.49	1.51	1.52	1.49	1.52	1.49	1.51	1.52	1.49	1.52	1.49	1.51	1.52	1.49	1.52

Table F-3 (continued)

	COMPACT					MEDIUM CAR					LARGE CAR				
	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030
Advanced Diesel	**2011**	**2016**	**2021**	**2025**	**2030**	**2010**	**2015**	**2020**	**2025**	**2030**	**2009**	**2014**	**2019**	**2025**	**2030**
Incremental Vehicle Price ($)	1151	933	897	885	922	1346	1065	1030	1003	1041	1477	1129	1092	1072	1108
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.30	1.35	1.40	1.40	1.43	1.30	1.35	1.40	1.40	1.42	1.30	1.34	1.39	1.40	1.42
Diesel Hybrid	**2014**	**2019**	**2024**	**2025**	**2030**	**2014**	**2019**	**2024**	**2025**	**2030**	**2014**	**2019**	**2024**	**2025**	**2030**
Incremental Vehicle Price ($)	1801	1440	1302	1299	1326	2089	1648	1482	1478	1504	2247	1769	1583	1579	1601
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	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	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
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	1.73	1.76	1.76	1.80	1.61	1.73	1.76	1.76	1.79	1.61	1.73	1.76	1.76	1.79
Gasoline Hybrid	**2007**	**2012**	**2017**	**2025**	**2030**	**2006**	**2011**	**2016**	**2025**	**2030**	**2009**	**2014**	**2019**	**2025**	**2030**
Incremental Vehicle Price ($)	1183	883	944	994	1028	1410	1003	1061	1128	1163	1453	1190	1217	1205	1237
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	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	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	1.00	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.85	0.95	0.95	0.95	0.95	0.85	0.95	0.95	0.95	0.95
Fuel Economy	1.31	1.35	1.45	1.52	1.55	1.32	1.34	1.44	1.51	1.54	1.32	1.40	1.49	1.51	1.54

Table F-3 (continued)

	COMPACT					MEDIUM CAR					LARGE CAR				
	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030
Plug-in HEV 40	**2020**	**2025**	**2030**	**2025**	**2030**	**2019**	**2024**	**2029**	**2025**	**2030**	**2021**	**2026**	**2031**	**2025**	**2030**
Incremental Vehicle Price ($)	2256	1611	1480	1611	1480	2628	1883	1717	1844	1720	2830	2026	1848	2174	1848
Range	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.10	1.05	1.03	1.05	1.03	1.10	1.06	1.04	1.05	1.03	1.10	1.05		1.05	1.03
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
Top Speed	0.95	1.00	1.00	1.00	1.00	0.95	1.00		1.00	1.00	0.95	1.00		1.00	1.00
Luggage Space	0.90	1.00	1.00	1.00	1.00	0.90	1.00		1.00	1.00	0.90	1.00		1.00	1.00
Fuel Economy	1.49	1.49	1.52	1.49	1.52	1.46	1.48	1.51	1.48	1.51	1.48	1.49	1.51	1.48	1.51

Table F-3 (continued)

	SMALL SUV					LARGE SUV					SMALL TRUCK				
	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030
Advanced Diesel	**2008**	**2013**	**2018**	**2025**	**2030**	**2007**	**2012**	**2017**	**2025**	**2030**	**2008**	**2013**	**2018**	**2025**	**2030**
Incremental Vehicle Price ($)	2912	2027	1788	1754	1801	3554	2487	2205	2154	2206	1918	1452	1427	1476	1537
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.78	1.77	1.76	1.79	1.85	1.78	1.78	1.76	1.79	1.85	1.43	1.48	1.57	1.63	1.69
Diesel Hybrid	**2011**	**2016**	**2021**	**2025**	**2030**	**2015**	**2020**	**2025**	**2025**	**2030**	**2012**	**2017**	**2022**	**2025**	**2030**
Incremental Vehicle Price ($)	3181	2330	2101	2077	2110	3899	2835	2551	2551	2584	2723	2044	1878	1871	1913
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	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	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
Top Speed	1.00	1.00	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
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.90	0.90	0.90	0.90
Fuel Economy	2.02	2.05	2.08	2.12	2.19	2.04	2.07	2.12	2.12	2.19	1.84	1.91	1.97	1.99	2.06
Gasoline Hybrid	**2007**	**2012**	**2017**	**2025**	**2030**	**2008**	**2013**	**2018**	**2025**	**2030**	**2010**	**2015**	**2020**	**2025**	**2030**
Incremental Vehicle Price ($)	2817	1994	1840	1834	1878	3414	2453	2260	2252	2300	2060	1631	1574	1580	1636
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	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	1.00	1.00	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	1.00	1.00	0.80	0.95	1.00	1.00	1.00
Fuel Economy	1.77	1.79	1.84	1.91	1.97	1.77	1.80	1.85	1.91	1.97	1.55	1.63	1.72	1.76	1.82

Table F-3 (continued)

	SMALL SUV					LARGE SUV					SMALL TRUCK				
	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030
Plug-in HEV 40	**2018**	**2023**	**2028**	**2025**	**2030**	**2020**	**2025**	**2030**	**2025**	**2030**	**2022**	**2027**	**2032**	**2025**	**2030**
Incremental Vehicle Price ($)	3493	2507	2264	2396	2269	4376	3142	2858	3142	2858	3083	2240	2052	2562	2052
Range	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.10	1.05	1.04	1.05	1.03	1.10	1.05	1.03	1.05	1.03	1.10	1.04		1.05	1.03
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
Top Speed	0.95	1.00	1.00	1.00	1.00	0.95	1.00	1.00	1.00	1.00	0.95	1.00		1.00	1.00
Luggage Space	0.90	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	0.90	1.00		1.00	1.00
Fuel Economy	1.81	1.85	1.91	1.87	1.94	1.83	1.87	1.94	1.87	1.94	1.70	1.75	1.78	1.72	1.78

Table F-3 (continued)

	CARGO (Incl. 2b) TRUCK					MINIVAN					LARGE VAN				
	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030
Advanced Diesel	**2006**	**2011**	**2016**	**2025**	**2030**	**2008**	**2013**	**2018**	**2025**	**2030**	**2006**	**2011**	**2016**	**2025**	**2030**
Incremental Vehicle Price ($)	2505	1833	1822	1930	2004	2759	1958	1740	1719	1765	2627	1884	1692	1654	1695
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.43	1.45	1.53	1.63	1.69	1.78	1.77	1.76	1.79	1.85	1.78	1.78	1.77	1.79	1.85
Diesel Hybrid	**2016**	**2021**	**2026**	**2025**	**2030**	**2013**	**2018**	**2023**	**2025**	**2030**	**2012**	**2017**	**2022**	**2025**	**2030**
Incremental Vehicle Price ($)	3649	2705	2450	2495	2495	3082	2262	2042	2036	2067	2947	2179	1973	1959	1986
Range	0.90	0.90	0.90	0.90	0.90	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	1.09	1.05	1.05	1.05	1.05	1.09	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
Top Speed	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
Luggage Space	0.80	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
Fuel Economy	1.90	1.96	2.00	1.99	2.06	2.03	2.06	2.10	2.12	2.19	2.02	2.05	2.09	2.12	2.19
Gasoline Hybrid	**2010**	**2015**	**2020**	**2025**	**2030**	**2009**	**2014**	**2019**	**2025**	**2030**	**2010**	**2015**	**2020**	**2025**	**2030**
Incremental Vehicle Price ($)	2711	2145	2064	2066	2133	2628	1949	1801	1798	1840	2495	1881	1738	1730	1768
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	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	0.90	0.90	0.90	0.90	0.90	0.75	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.80	0.95	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.55	1.63	1.72	1.76	1.82	1.77	1.81	1.86	1.91	1.97	1.77	1.82	1.87	1.91	1.97

Table F-3 (continued)

	CARGO (Incl. 2b) TRUCK					MINIVAN					LARGE VAN				
	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030	Market Intro.	Price Success	Price Mature	2025	2030
Plug-in HEV 40	**2020**	**2025**	**2030**	**2025**	**2030**	**2020**	**2025**	**2030**	**2025**	**2030**	**2021**	**2026**	**2031**	**2025**	**2030**
Incremental Vehicle Price ($)	4230	3045	2785	3045	2785	3384	2429	2216	2429	2216	3223	2318	2114	2492	2114
Range	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10		1.10	1.10
Maintenance Cost	1.10	1.05	1.03	1.05	1.03	1.10	1.05	1.03	1.05	1.03	1.10	1.05		1.05	1.03
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
Top Speed	0.95	1.00	1.00	1.00	1.00	0.95	1.00	1.00	1.00	1.00	0.95	1.00		1.00	1.00
Luggage Space	0.90	1.00	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	0.90	1.00		1.00	1.00
Fuel Economy	1.68	1.72	1.78	1.72	1.78	1.83	1.87	1.94	1.87	1.94	1.84	1.88	1.94	1.87	1.94

Table F-3 (continued)

	2-SEATER					MINI-COMPACT					SUB-COMPACT					COMPACT				
Advanced Gasoline	**2010**	**2015**	**2020**	**2025**	**2030**	**2010**	**2015**	**2020**	**2025**	**2030**	**2010**	**2015**	**2020**	**2025**	**2030**	**2010**	**2015**	**2020**	**2025**	**2030**
Incremental Vehicle Price ($)	32	392	621	608	666	29	363	575	565	622	27	333	525	513	561	25	306	487	481	528
Range																				
Maintenance Cost																				
Acceleration																				
Top Speed																				
Luggage Space																				
Fuel Economy	1.01	1.10	1.20	1.20	1.22	1.01	1.10	1.20	1.20	1.22	1.01	1.10	1.20	1.20	1.22	1.01	1.10	1.20	1.20	1.22

	MEDIUM CAR					LARGE CAR				
Advanced Gasoline	**2010**	**2015**	**2020**	**2025**	**2030**	**2010**	**2015**	**2020**	**2025**	**2030**
Incremental Vehicle Price ($)	76	363	553	539	589	82	390	593	576	627
Range										
Maintenance Cost										
Acceleration										
Top Speed										
Luggage Space										
Fuel Economy	1.01	1.10	1.19	1.19	1.22	1.01	1.10	1.19	1.19	1.22

Table F-3 (continued)

Advanced Gasoline	SMALL SUV 2010	2015	2020	2025	2030	LARGE SUV 2010	2015	2020	2025	2030	SMALL TRUCK 2010	2015	2020	2025	2030	CARGO (Incl. 2b) TRUCK 2010	2015	2020	2025	2030
Incremental Vehicle Price ($)	1397	1052	977	938	957	1713	1289	1195	1152	1171	846	855	956	926	950	1113	1125	1253	1211	1238
Range																				
Maintenance Cost																				
Acceleration																				
Top Speed																				
Luggage Space																				
Fuel Economy	1.29	1.31	1.33	1.32	1.34	1.29	1.31	1.33	1.32	1.34	1.17	1.26	1.34	1.34	1.35	1.17	1.26	1.34	1.34	1.35

Advanced Gasoline	MINIVAN 2010	2015	2020	2025	2030	LARGE VAN 2010	2015	2020	2025	2030
Incremental Vehicle Price ($)	1343	1022	954	919	937	1288	982	917	885	900
Range										
Maintenance Cost										
Acceleration										
Top Speed										
Luggage Space										
Fuel Economy	1.29	1.31	1.33	1.32	1.34	1.29	1.31	1.33	1.32	1.34

Table F-4. ATV Attributes for Input to MARKAL

(Units are ratios to the conventional gasoline vehicles of the specific year. Prices are in 2004 dollars.)

Ratios to Conventional Vehicles		2010	2020	2025	2030	2035	2050
CARS							
Advanced Gasoline	MPG	1.01	1.19	1.20	1.22	1.25	1.26
	Incremental Price						1.020
Diesel	MPG	1.29	1.40	1.40	1.43	1.46	1.58
	Incremental Price			1.022			1.025
Gasoline HEV	MPG	1.32	1.51	1.52	1.55	1.58	1.72
	Incremental Price			1.039			1.030
Diesel HEV	MPG	1.51	1.76	1.76	1.79	1.83	1.99
	Incremental Price			1.043			1.040
PHEV40	MPG on gasoline	1.29	1.48	1.49	1.52	1.55	1.68
	kWh/mil	0.20	0.20	0.20 1.056	0.20	0.20	0.20
	Incremental Price						1.045
LIGHT TRUCKS							
Advanced Gasoline	MPG	1.25	1.33	1.33 1.063	1.34	1.36	1.33
	Incremental Price						1.030
Diesel	MPG	1.67	1.70	1.74	1.80	1.86	1.93
	Incremental Price			1.034			1.035
Gasoline HEV	MPG	1.70	1.82	1.86	1.92	1.99	2.07
	Incremental Price			1.061			1.040
Diesel HEV	MPG	1.95	2.03	2.07	2.15	2.22	2.31
	Incremental Price			1.064			1.050
PHEV40	MPG on gasoline	1.67	1.78	1.82	1.89	1.95	2.02
	kWh/mil	0.26	0.26	0.26 1.073	0.26	0.26	0.26
	Incremental Price						1.055
				1.081			

Estimation of ATV MPG Estimates

This section explains how PSAT results have been used to develop the fuel economy inputs to the GPRA models. The same methodology was applied to estimate fuel cell vehicles' (FCVs) fuel economy. The section mentions FCVs, but we do not present the FCV MPG estimates in this appendix.

1. There are two GPRA models: NEMS and MARKAL. The NEMS model requires characterization of six cars and six light trucks (LTs) for each technology to 2030. The MARKAL model requires characterization of an average car and an average LT for each technology to 2050. **Table F-5** summarizes the vehicle classes used in both models.

Table F-5. Vehicle Classes Used in Various Models

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

2. The PSAT model itself only provides fuel economy estimates for four of the 12 vehicle classes required by NEMS. The four classes in PSAT are also presented in **Table F-5**: They include compact and midsize cars, a SUV, and a pickup. PSAT results for those four classes, thus, must be adjusted 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) were provided for five vehicle technologies (advanced gasoline, gasoline HEV, advanced diesel, diesel HEV, and FCV) in three vehicle classes types (midsize car, SUV, and pickup) in two years (2010 and 2020) (Ref. 3). "Low," "high," and "average" results were provided. The "high" results are the only one of the three sets of results that represents 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 for the period to 2050 are developed. 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 three vehicle types (compact car, midsize car, and SUV) in four years (2010, 2020, 2035, and 2050) (Ref. 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. Given the new vehicle fuel economies developed for advanced technologies in No. 3 and for comparable conventional vehicles in No. 4, the final fuel economy ratios or 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 pickup) in several years (2010, 2020, 2025, 2030, 2035, and 2050) are estimated.

6. For NEMS, the fuel economy X factor of the compact cars is assumed to apply also to the mini-compact, subcompact, and two-seater vehicles because these vehicle classes have a lot in common with respect to vehicle attributes, such as performance. The X factor of the midsize cars is assumed to apply to medium and large cars because they are similar. The X factor of the SUV (which is a large SUV according to the NEMS classification) is assumed to apply to large and small SUVs and all vans because vans are closer to SUVs than to pickups. The X factor of the pickup (which is a large pickup, according to the NEMS classification) is assumed to apply to both small and large pickups.

7. The fuel economy estimates finalized in No. 5 and No. 6 are for 2010, 2020, 2025, and 2030. For NEMS, we also need to provide estimates for intervening years. For those intervening years, we used linear interpolation to estimate the X factors.

8. As stated above, MARKAL uses only one aggregate car class and one aggregate light-truck class. We examined current sales volumes of the six different car classes and six different light-truck classes. Based on that examination, we weighted the compact and midsize cars 50-50 to estimate the X factor of an average car; and we weighted the SUV and pickup 67-33 to estimate the X factor of an average light truck. EIA projects very little change in class shares over the 2006 to 2030 period; therefore, we do not project any change in this analysis.

9. The two sets of PSAT results used to estimate ATV MPG estimates did not include results for plug-in hybrids (PHEVs). Instead, we assumed that PHEV40s, when operating on the engine, average 98% of the fuel economy achieved by HEVs. We assumed that PHEV40s, when operating on the battery, average 0.2 kWh/mile (cars) and 0.26 kWh/mile (light trucks). Travel on battery is assumed to be 40% of total travel.

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, which is 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 7.5% discount rate (This IRS discount rate was selected in 2000 when this payback model was built. If we were to use the 2006 IRS discount rate, it would be 5.8%.), and the following fuel prices (which are from the *AEO2006* projections) per gasoline gallon equivalent: $2.08 for gasoline, $2.03 for diesel, $2.82 for H2, and $3.11 for electricity. Incremental prices are higher in the early years of market introduction. In fact, we developed three sets of prices for each class of vehicle for input to NEMS. Prices were 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 was “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 weighted the incremental prices estimated for each technology in 2030 in the same manner that we weighted the fuel economy estimates as described in No.10 of Section 1.3.1. We then assumed a gradually declining incremental price to 2050 for each technology.

ATV Market-Penetration Methodology

Brief descriptions of how NEMS and MARKAL projected new vehicle technology penetration using these vehicle attributes can be found in the main body of the FY 2008 budget request’s benefits documentation.

Heavy Vehicles

Significant Changes from Previous Analysis

Two significant changes have been made in this year's benefit estimates. One involves removing two technology activities from the analysis. The other involves modifying the model that determines market penetration.

The FCVT program had a reduction in their budget for FY08, so two Heavy Truck (HT) technologies were removed from their portfolio: 1) hybrid heavy trucks and 2) weight reduction. The dropping of these two activities (rather than others) was due, in part, to the fact that these activities had relatively small benefits in the GPRA07 benefits estimates provided to the FCVT program last year.

The TRUCK model was also changed so that there are now two types of Class 7 and 8 trucks: 1) Combinations and 2) Single Unit. This replaces the three types used previously. This was done so that the HT classes would be the same as those for which data are available from DOT and that were used in the HT VISION model.

The Baseline ("without DOE RD3" case)

The projection that is in *AEO2006* is accepted as the appropriate baseline. It has heavy-truck on-road mpg growing slightly from 6.0 in 2004 to 6.8 in 2030. This is an increase of 15% without the EERE program.

Program Outputs

The technologies for which benefits are estimated for heavy trucks are the three shown in **Tables F-6 and F-7** for 2010 and for 2020-2050.

Table F-6. Efficiency Improvement Contributions – 2010

Number	Item	Type 1		Type 2	
		Fuel Economy, mpg	Single Technol. Benefit, %	Fuel Economy, mpg	Single Technol. Benefit, %
		A	B	A	B
1	Baseline	6.1	0.0%	6.7	0.0%
2	Auxiliary Loads Electrification	6.1	0.5%	6.8	2.5%
3	Engine Efficiency, WHR	7.6	24.6%	8.2	22.9%
4	Aerodynamic Load Reduction	6.3	3.0%	6.8	1.9%
5	Sum of Individual Benefits	--	28.1%		27.4%
6	**Combined Effects**	**7.9**	**128.9%**	**8.6**	**128.5%**

Table F-7: Efficiency Improvement Contributions – 2020-2050

Number	Item	Type 1 Fuel Economy, mpg	Type 1 Single Technol. Benefit, %	Type 2 Fuel Economy, mpg	Type 2 Single Technol. Benefit, %
		A	B	A	B
1	Baseline	6.1	0.0%	6.7	0.0%
2	Auxiliary Loads Electrification	6.2	0.9%	7.0	4.3%
3	Engine Efficiency, WHR	8.8	44.3%	9.4	40.9%
4	Aerodynamic Load Reduction	6.5	6.1%	6.8	1.9%
5	Sum of Individual Benefits	--	51.4%		47.1%
6	**Combined Effects**	**9.4**	**154.6%**	**10.0**	**149.8%**

The sources and basis for these assumptions are as described below:

Auxiliary Loads Reduction is the improvement in vehicle fuel economy by changing some of the vehicle functions from mechanical to electrical. For example, the brake air compressor, oil pump, and water pump can be energized electrically, instead of mechanically, and be made more efficient.

(See http://www1.eere.energy.gov/vehiclesandfuels/pdfs/success/more_electric_truck_04.pdf)

Engine Efficiency is the improvement in vehicle fuel economy by making the diesel engine more efficient. This is done by optimizing the engine design, improving the waste heat recovery (WHR), using advanced fuel injection and engine control strategies, reducing friction losses, and using robust sensors for control systems.

(See http://www1.eere.energy.gov/vehiclesandfuels/technologies/engines/printable_versions/heavy_truck_engine.html)

Aerodynamic Load Reduction is the improvement in vehicle fuel economy through the alteration of the shape of heavy trucks to decrease the aerodynamic resistance (drag) on them as they travel at highway speeds. (See http://eed.llnl.gov/aerodrag/pdf/aerodrag2.pdf)

Translating Program Outputs to Market Outcomes

This section describes the assumptions and market characterization used for estimating benefits for the Heavy Vehicle Technologies activities. 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 (Davis 2006):
    - Class 3: 10,001 – 14,000
    - Class 4: 14,001 – 16,000
    - Class 5: 16,001 – 19,500
    - Class 6: 19, 501 – 26,000
    - Class 7 : 26,001 – 33,000
    - Class 8: 33,001 lbs and up,
- Identifying technology goals associated with the FCVT Program,
- Estimating the market potential of technologies that improve fuel efficiency and/or use alternative fuels.

This determines the petroleum savings associated with the advanced heavy vehicle technologies. These estimates are developed at the program-element level to assist project prioritization.

In the recent past, the Heavy Vehicles 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 FY08. These changes are the result of a planning effort that occurred during FY05 and FY06.

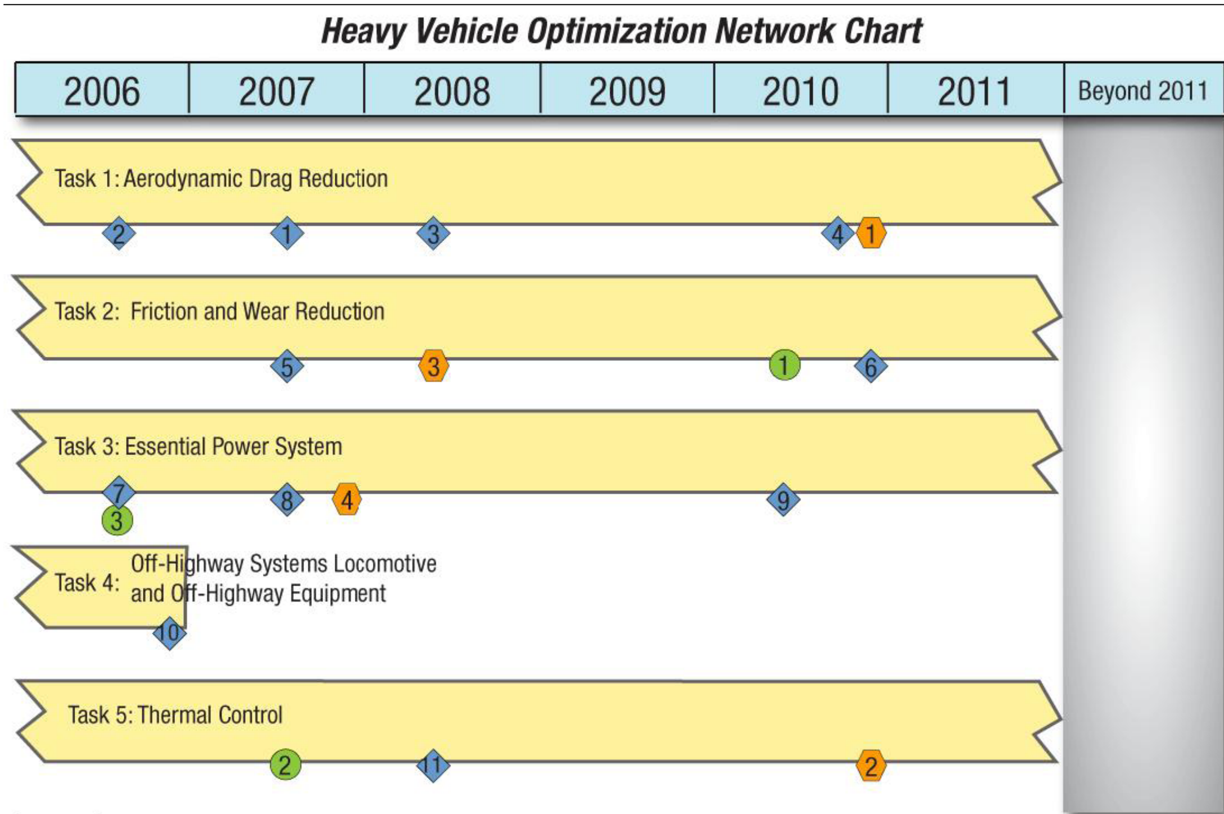
The Heavy Vehicle Activities supported by FCVT are not represented in the NEMS model. The details on mileage distribution and varying payback years are also not included in the NEMS model. These are the reasons why the EERE TRUCK and associated models are used to estimate the market penetration of advanced heavy vehicle technologies. NEMS and MARKAL used the results to estimate the benefits reported in the FY 2008 budget request. The FCVT approach and outputs for the Heavy Vehicles Optimization activity is illustrated in **Exhibit F-8**.

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 from the Department of Transportation (http://www.census.gov/svsd/www/vius/products.html) were examined for all vehicles in use and vehicles 2 years old or less (Argonne National Laboratory, PSAT). Subsequently, the Heavy Truck vehicle market was 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 use patterns (as compared to vehicle use). The vehicle type segments comprise the vehicle configurations listed below:

- Type 1, Class 7 and 8 – Single unit, Conventional Powerplant (Diesel and Gasoline);
- Type 2, Class 7 and 8 – Combination units (e.g., tractor trailers), Conventional Powerplant (Diesel only)

Exhibit F-8. Heavy Vehicles Optimization Network Chart



Legend

Milestone	Technology Program Output	Supporting Input
1. Road test available aerodynamic drag reduction devices 2. Transfer data to computational fluid dynamics team 3. Demonstrate prediction capability with industry partners 4. 15% reduction in aerodynamic drag using active devices 5. Identify candidate methods to mitigate failures 6. Select surface modification technologies and optimized lubricant-surface interactions 7. Electrification of accessory components in Class 8 8. Electrification complete for classes 3-6 9. Class 7/8 truck cooling system 10. Validate systems to increase fuel efficiency 11. Bench-test prototype thermal control	1. Drag reduction technology to AHHPS subcontracts and to industry 2. Thermal control technology to industry 3. Technical data on surface modification technology to reduce friction to Heavy Truck Engine R&D 4. Fuel formulation constraint for APUs to Advanced Fuels R&D	1. Lubricants optimized for use with specific surface modification methods to increase engine efficiency and reduce friction and wear 2. Accurate measurements of increased thermal loading on cooling systems as a result of increased EGR to meet emissions requirements 3. Thermal comfort tools available from Light Vehicle Ancillary Systems R&D

The lower-speed characteristics of Type 1 trucks greatly reduce the potential efficiency benefits in that sector compared to Type 2. 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. However, electrification of accessories may have a greater effect in the Type 1 sector.

Distances traveled by Type 2 vehicles are typically greater than Type 1, which implies that the typical speeds are higher. These characteristics make them a somewhat better market sector for speed-dependent measures such as advanced tires. In general, Type 2 vehicles are the best candidates for technologies that reduce drivetrain losses or vehicle losses.

Refueling characteristics, i.e., central-source or noncentral-source, also are considered in the market characteristics, as it is easier to deploy an alternative fuel for centrally refueled vehicles.

Forty 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 (Davis, S. 2001; Davis, S. 2005; Bureau of Census, 1999).

Exhibit F-9 shows the distribution of annual travel for the two types of Class 7 and 8 vehicles. Type 2 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 130,000-mile segment.

Exhibit F-10 shows the vehicle use pattern for Local or Type 1 Heavy Trucks. The distributions based both on vehicles and vehicle-miles traveled are indicated. **Exhibit F-11** shows the same information as **Exhibit F-2,** but for Type 2 trucks. For Type 1, the distribution peaks in the 20,000- to 39,000-mile segment. Similar information for gasoline and diesel medium trucks is shown in **Exhibit F-12.**

An analysis of vehicle use patterns showed that centrally refueled vehicles travel less than noncentrally refueled vehicles. For the latter, 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.

Exhibit F-9. Class 7 and 8 Trucks – Single and Combination Units: Distribution of Trucks and Trucks Vehicle Miles

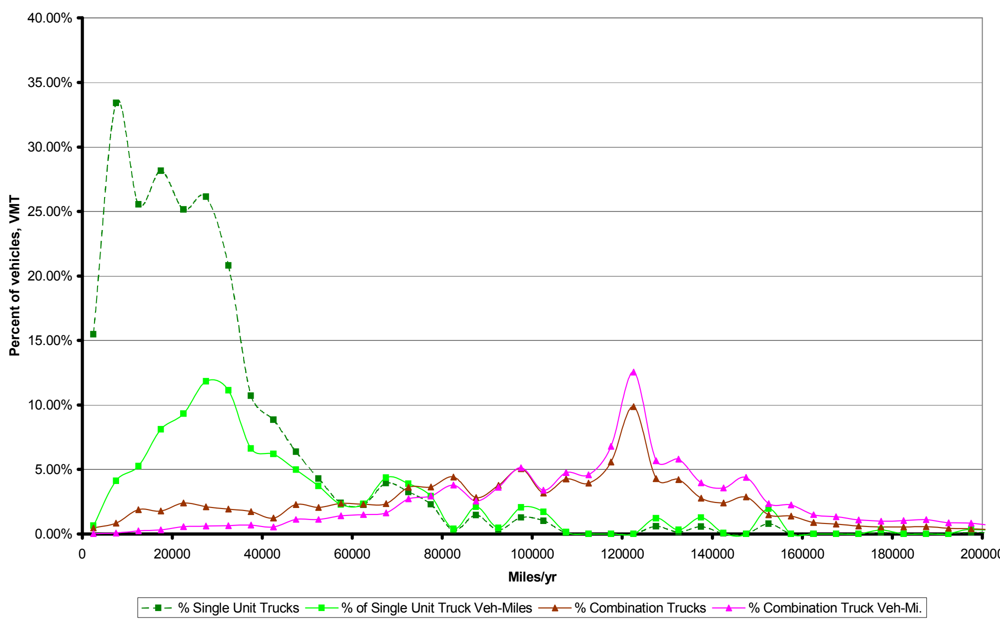


Exhibit F-10. Class 7 and 8 Trucks – Combination Units: Distribution of Trucks and Truck Vehicle Miles

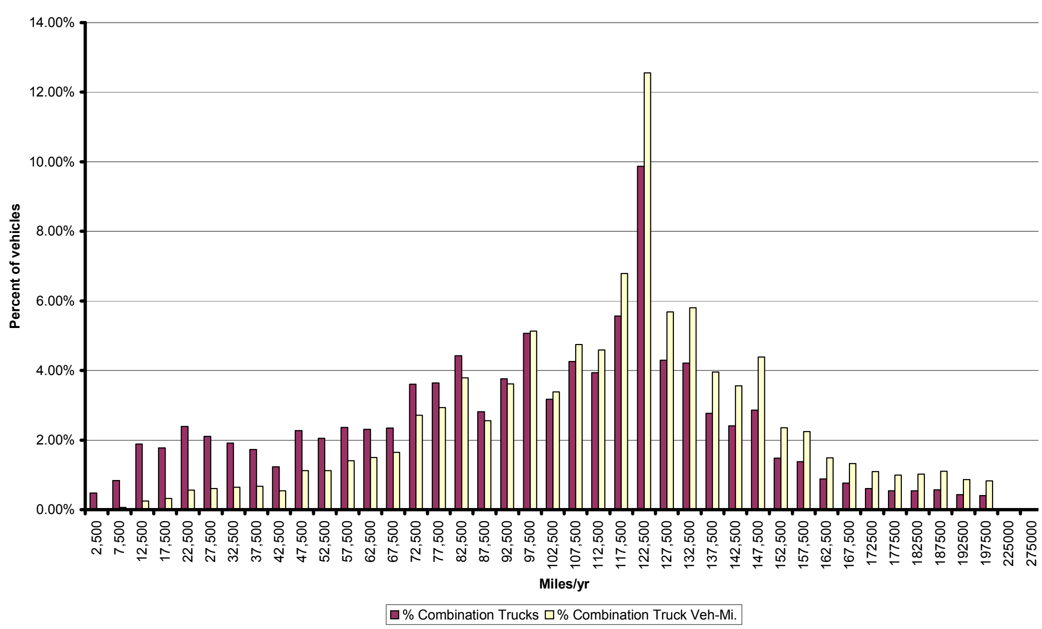


Exhibit F-11. Distribution of Class 7 and 8 Single-Unit Trucks

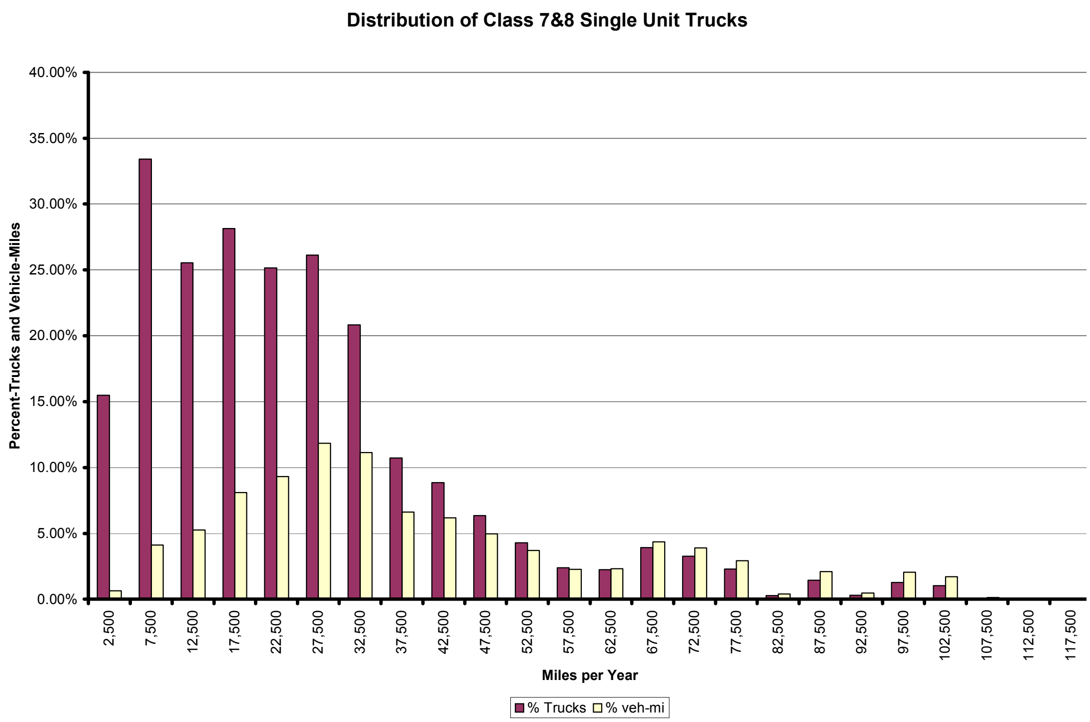
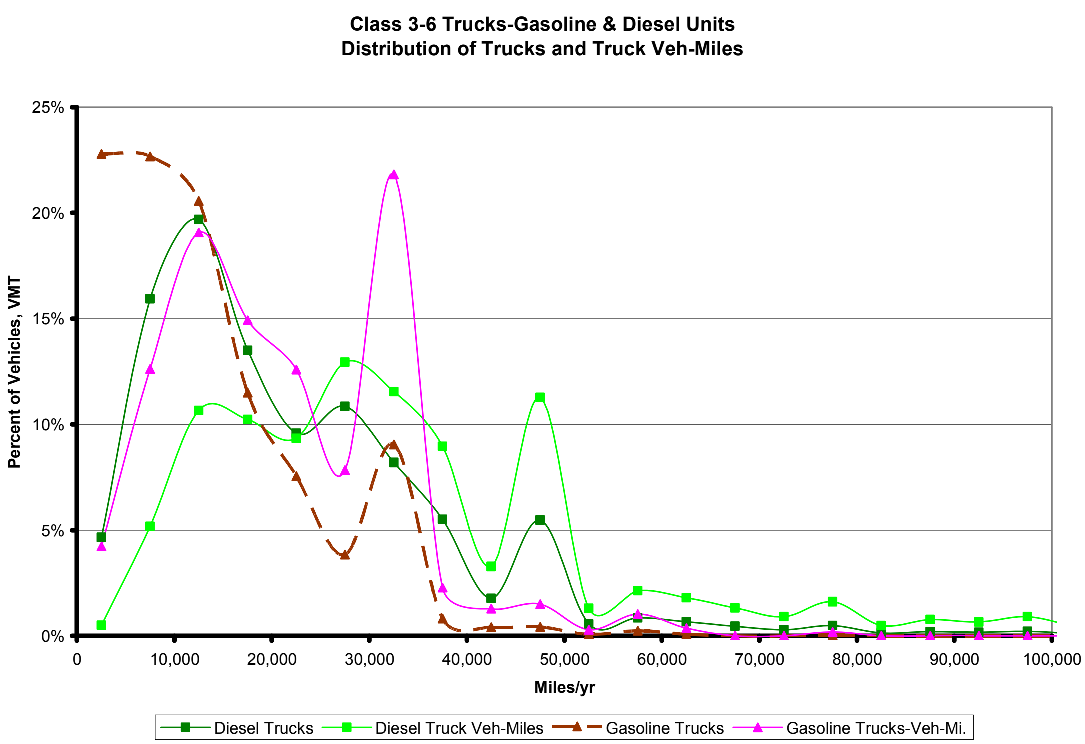


Exhibit F-12. Travel Distributions for Classes 3–6 Trucks



Discussion of Inputs

Heavy vehicle market characteristics that are pertinent to the analysis are summarized in **Table F-8**. In the medium-truck market segment (Classes 3 through 6), all vehicle types, with the exception of automobiles 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 three truck types was updated using VIUS 2002 data (Bureau of the Census 1999).

Table F-8: Heavy-Vehicle Characteristics (2002)

Vehicle Type	Class 7 & 8, Type 1	Class 7 & 8, Type 2	Class 3 through 6 Diesel	Class 3 through 6 Gasoline	Comments
Body Types	**Combination Units**	**Single Units**	**- -**	**- -**	
Fuel Economy (Baseline)	6.10	6.70	8.90	9.40	
Fuel Economy Improvement, %	155%	150%	145%	144%	Combined effect of FCVT Technologies, 2020-2050
Average Miles Traveled, miles	96,300	13,000	23,100	11,800	
Portion of Heavy Truck Fuel Use, %	72%	13%	11%	4%	Estimated--Year 2005
Portion of Vehicle Travel < 50 k Miles,	5%	68%	84%	98%	
Portion of Vehicle Travel 50 k to 100 k	26%	25%	12%	2%	
Portion of Vehicle Travel >100 k	69%	7%	4%	0%	

Key Factors Shaping Market Adoption of Technology

Table F-9 shows the payback distribution assumed in the TRUCK model. This payback distribution was generated from an American Trucking Association's survey conducted in 1997 to determine the payback investment criteria for an investment in energy conservation. The survey of 224 motor carriers revealed that paybacks of one to four years were acceptable for energy-conserving technologies. The survey found that, for example, 16.4% of the truck operators responding require a payback of one year on an investment.

Based on those findings, we modeled the market acceptance of the various technologies based on payback performance. The average heavy truck is in use for 28 years (Davis 2006, p. 3-27). Average fuel economy increased from 5.6 mpg in 1992 to 5.8 mpg in 2002 (Davis 2006, p. 5-6).

Table F-9. ATA Survey Payback Preference Distribution

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

Effects of Lower Emissions on Heavy Vehicle Fuel Economy

The Environmental Protection Agency (EPA) has initiated regulation of emissions from Heavy Trucks. Industry is responding by modifying engine technology and diesel fuel=refining processes. Some reduction in fuel economy with the new engines is also expected as the combustion process optimization is addressing reduction of emissions. These changes will impose both operating and capital costs on truck operators, because meeting the emissions requirements typically penalizes fuel economy.

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 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 NOx and $PM_{2.5}$ 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.

In addition, in December 2000, EPA published new emission standards for on-road, heavy-duty diesel engines that would take effect beginning in 2007. The standards will have emission levels of PM at 0.01 g/bhp-hr, NO_x at 0.20 g/bhp-hr, and HC at 0.14 g/bhp-hr. The new standards apply to diesel-powered vehicles with gross vehicle weight (GVW) of 14,000 pounds or more. The PM standard applies to all on-road heavy and medium-duty diesel engines. Starting in 2007 and running through 2009, the EPA is giving the manufacturers some flexibility in meeting the new standards. They have the option of meeting the average of the 2004 and 2007 NO_x and HC emissions levels (1.1g/bhp-hr). In addition, if manufacturers produced low-emission engines in 2006, then that amount can be deducted from their 2007 requirements.

The EPA rule-making process requires 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 be adopted, regardless of 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 estimated the increase in annual nonfuel 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_X 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 (Clean Air Task Force 2006, EIA 2001, Vyas 2002).

Methodology and Calculations: Overview

The analysis of the benefits expected from achieving the goals of the Heavy Vehicle Technologies Subprogram was 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 (Argonne National Laboratory, PSAT);
- Truck operator investment requirements—as provided by a survey of owner-operators performed by the American Trucking Association in 1997 (American Trucking Association 1997);

- 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 (EIA 2006). This information is used in the market penetration methodology of the TRUCK model, which is needed to estimate future fuel economies. Fuel prices beyond 2030 are based on extrapolating the prices in AEO in the 2030 to 2050 period using that average annual change from 2020 to 2030.

The methodology involves the definition of the energy conservation or displacement and cost attributes of the advanced technologies being fostered by FCVT, 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 (Singh 2003, Moore 2005):

- HTEB – Heavy-Truck Energy Balance Model (Version 2.0)
- TRUCK 3.0 – Heavy-Vehicle Market Penetration Model
- VISION 2006
- Heavy Truck Summary (HVS) report generator.

The relationship of these four models is indicated in **Exhibit F-13.**[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. This steady-state model accounts for energy losses based on user-selected inputs of vehicle use. The fuel economies of new advanced heavy-vehicle technologies estimated with the HTEB model are presented in **Table F-10.**

[1] The HTEB was developed by William Shadis and James Moore of TA Engineering Inc.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 John 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.

Table F-10. Advanced Heavy-Vehicle Characterization (New Vehicles)

	Characteristic	2010	2020	2030	2040	2050
1	Fuel Economy Class 7-8, Combination (Type 1) mpg Multiplier	1.29	1.55	1.55	1.55	1.55
2	Fuel Economy Class 7-8, Single Unit (Type 2) mpg Multiplier	1.28	1.50	1.50	1.50	1.50
3	Fuel Economy Class 3-6 Gasoline, mpg Multiplier	1.24	1.45	1.45	1.45	1.45
4	Fuel Economy Class 3-6- Diesel, mpg Multiplier	1.24	1.44	1.44	1.44	1.44
5	Class 7-8, Iincremental Cost, $	$ 30,000	$ 15,000	$ 10,000	$ 10,000	$ 10,000
6	Class 3-6 Gasoline, Incremental Cost, $	$ 5,000	$ 2,000	$ 1,500	$ 1,500	$ 1,500
7	Class 3-6 Diesel, Incremental Cost, $	$ 7,500	$ 2,500	$ 2,000	$ 2,000	$ 2,000

Exhibit F-13. Heavy-Truck Benefits Analysis Models

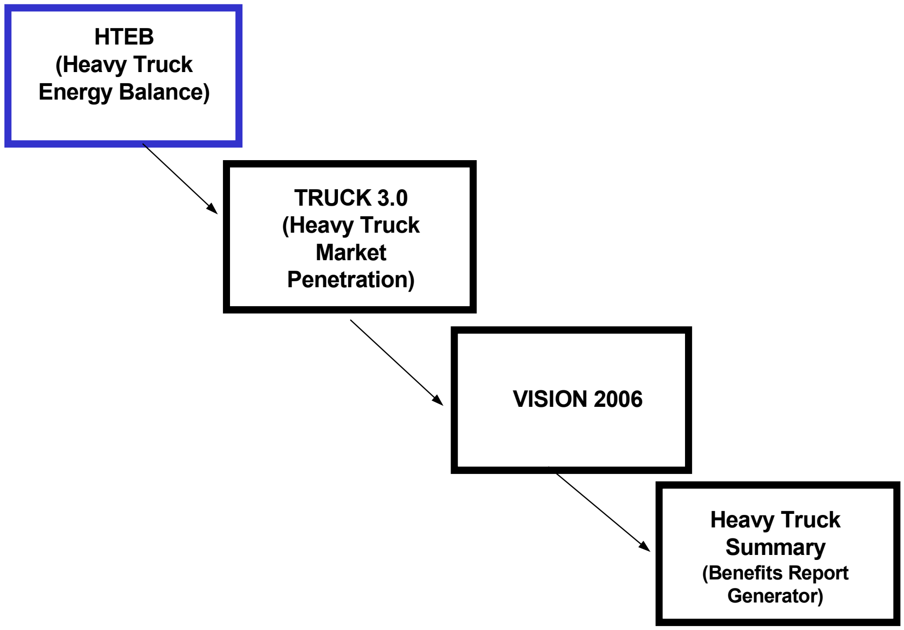


Table F-11. Example Price and Efficiency Schedule for Advanced Technologies

	Class 7 & 8 Vehicle Assumptions			
	Type 1 Non-Hybrid Trucks		*Type 2 Non-Hybrid Trucks*	
Year	Non-Hybrid Measures Cost (2003$)	Efficiency Ratio	Non-Hybrid Measures Cost (2003$)	Efficiency Ratio
2006	42,000	1.138	42,000	1.137
2010	30,000	1.289	30,000	1.285
2015	20,000	1.289	20,000	1.285
2020	15,000	1.546	15,000	1.498
2025	10,000	1.546	10,000	1.498
2030	10,000	1.546	10,000	1.498
2035	10,000	1.546	10,000	1.498
2040	10,000	1.546	10,000	1.498
2045	10,000	1.546	10,000	1.498
2050	10,000	1.546	10,000	1.498

The price estimates for these vehicles are also presented in **Table F-10.** All prices are in 2004 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 **Table F-10** technologies in the Long Haul vehicle application is indicated in **Table F-11**. 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 3.0.** 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.

The TRUCK 3.0 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**.** The TRUCK model market penetration calculation method for Class 7 and 8, Type 1 vehicles is described in **Exhibit F-14**.

Th**e** market penetration results are supplied through a link to the **VISION** model (Singh 2003). 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 2030 that baseline is the same as that of the AEO.

For the period from 2030 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 and 2 Heavy Trucks or Medium Trucks, the fuel economy multipliers generated by Truck 3.0 are aggregated on both a sales and VMT-weighted basis for input to VISION. These aggregated fuel economy multipliers are provided in **Exhibit 15**. Specifically, the factors in cells that are highlighted in yellow are provided for input to the NEMS and MARKAL models.

The baseline fuel economies for each market sector are determined based on the AEO fuel economy projection (extrapolated to 2050) using a calculation methodology to determine what the fuel economy of each market sector needs to be consistent with AEO. The market penetration estimates presented in Exhibit 16 are the factors ultimately used in the EERE-wide integrated analysis.

Finally, the **Heavy Truck Summary** report generator summarizes the first order benefits for the period covering 2000 through 2050. Benefits 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 FCVT benefits cannot be generated by the NEMS and MARKAL models.

Exhibit 14: Truck Payback Algorithm—Type 1 Trucks (Combinations)

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**	Results from running the calculation for centrally refueled Type 1 trucks 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 15: Advanced Heavy Vehicle Market Penetration and Fuel Economy Results for NEMS

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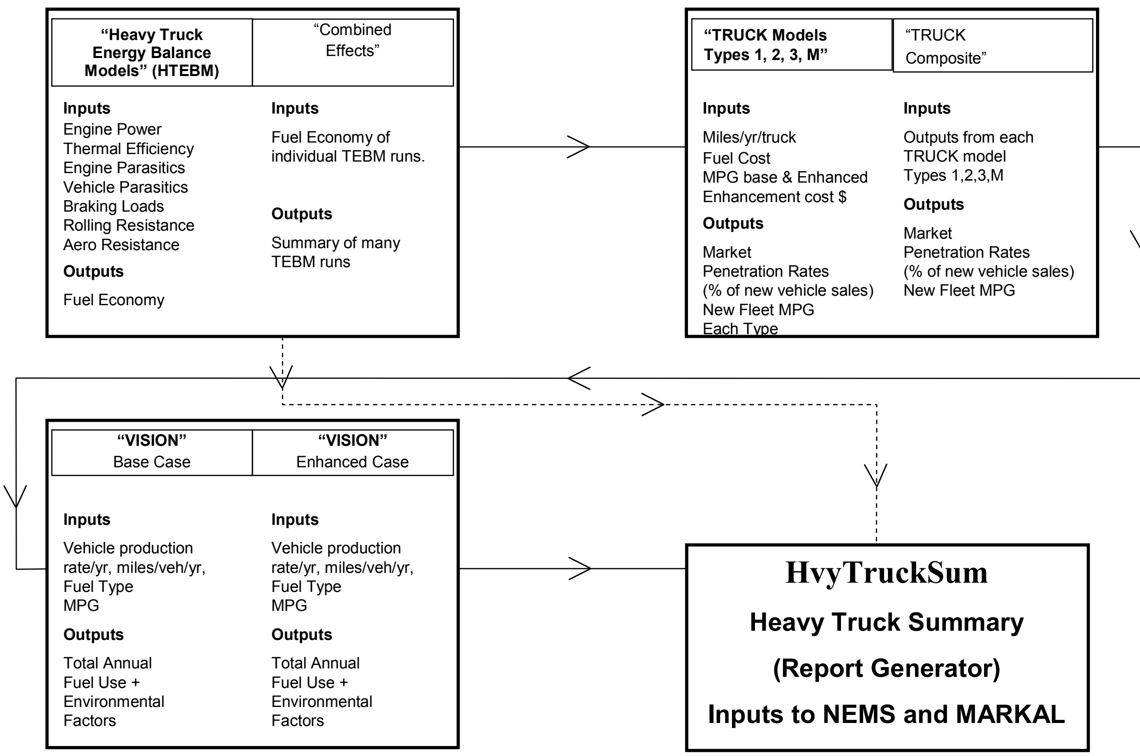
	Class 7 & 8						Class 3 - 6					
Year	Combined Market Penetration, % VMT	Base MPG (VISION-Adusted) in gasoline equivalent gallons	Fuel Economy Multiplier only for trucks with new techology which achieve the market penetration shown in Column 2 and Relative to 2005 Truck	Fuel Economy for All New Technology Sales, mpg	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)	Combined Market Penetration, % VMT	Base MPG (VISION Adjusted) in gasoline equivalent gallons	Fuel Economy Multiplier only for trucks with new techology which achieve the market penetration shown in Column 10 Relative to 2005 Truck	Fuel Economy for All New Technology Sales, mpg	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
2000	0%	6.15	1.00	6.15	6.15	1.00	0%	8.83	1.00	8.59	8.83	1.00
2001	0%	6.15	1.00	6.15	6.15	1.00	0%	8.80	1.00	8.59	8.80	1.00
2002	0%	6.15	1.00	6.15	6.15	1.00	0%	8.77	1.00	8.59	8.77	1.00
2003	0%	6.15	1.00	6.15	6.15	1.00	0%	8.73	1.00	8.59	8.73	1.00
2004	0%	6.15	1.00	6.15	6.15	1.00	0%	8.70	1.00	8.59	8.70	1.00
2005	0%	6.15	1.00	6.15	6.15	1.00	0%	8.59	1.00	8.59	8.59	1.00
2006	0%	6.15	1.01	6.22	6.15	1.00	0%	8.57	1.01	8.69	8.57	1.00
2007	0%	6.15	1.02	6.29	6.15	1.00	0%	8.56	1.02	8.79	8.56	1.00
2008	0%	6.15	1.03	6.36	6.15	1.00	0%	8.56	1.03	8.88	8.56	1.00
2009	0%	6.15	1.05	6.43	6.15	1.00	0%	8.55	1.05	8.98	8.55	1.00
2010	0%	6.15	1.06	6.50	6.15	**1.00**	0%	8.55	1.06	9.08	8.56	**1.00**
2011	0%	6.15	1.11	6.80	6.15	1.00	1%	8.55	1.10	9.41	8.56	1.00
2012	0%	6.15	1.15	7.10	6.15	1.00	1%	8.55	1.13	9.74	8.57	1.00
2013	0%	6.15	1.20	7.39	6.15	1.00	1%	8.56	1.17	10.07	8.57	1.00
2014	1%	6.16	1.25	7.69	6.16	1.00	2%	8.56	1.21	10.40	8.59	1.00
2015	2%	6.17	1.42	8.73	6.20	1.00	3%	8.56	1.34	11.49	8.62	1.01
2016	4%	5.96	1.47	9.02	6.04	1.01	6%	8.57	1.36	11.66	8.71	1.02
2017	9%	6.00	1.52	9.32	6.19	1.03	10%	8.57	1.38	11.84	8.82	1.03
2018	14%	6.03	1.56	9.62	6.35	1.05	17%	8.57	1.40	12.01	9.01	1.05
2019	24%	6.03	1.61	9.91	6.66	1.10	32%	8.57	1.42	12.19	9.46	1.10
2020	43%	6.04	1.54	9.47	7.14	**1.18**	41%	8.57	1.44	12.36	9.82	**1.15**
2021	43%	6.04	1.54	9.47	7.17	1.19	44%	8.62	1.44	12.36	9.95	1.15
2022	51%	6.08	1.54	9.47	7.45	1.22	45%	8.62	1.44	12.36	9.96	1.16
2023	55%	6.09	1.54	9.47	7.56	1.24	45%	8.62	1.44	12.36	9.99	1.16
2024	57%	6.10	1.54	9.47	7.65	1.26	47%	8.62	1.44	12.36	10.06	1.17
2025	63%	6.16	1.54	9.47	7.91	1.28	54%	8.82	1.44	12.36	10.45	1.18
2026	63%	6.16	1.54	9.47	7.91	1.28	56%	8.82	1.44	12.36	10.49	1.19
2027	64%	6.16	1.54	9.47	7.92	1.29	56%	8.82	1.44	12.36	10.49	1.19
2028	63%	6.16	1.54	9.47	7.91	1.28	56%	8.82	1.44	12.36	10.49	1.19
2029	64%	6.16	1.54	9.47	7.92	1.29	57%	8.82	1.44	12.36	10.55	1.20
2030	64%	6.17	1.54	9.47	7.93	**1.28**	59%	8.82	1.44	12.36	10.61	**1.20**
2031	64%	6.18	1.54	9.47	7.94	1.28	61%	8.85	1.44	12.36	10.72	1.21
2032	64%	6.20	1.54	9.47	7.95	1.28	66%	8.87	1.44	12.36	10.89	1.23
2033	64%	6.21	1.54	9.47	7.96	1.28	66%	8.90	1.44	12.36	10.91	1.23
2034	64%	6.22	1.54	9.47	7.97	1.28	66%	8.93	1.44	12.36	10.92	1.22
2035	64%	6.24	1.54	9.47	7.99	1.28	66%	8.95	1.44	12.36	10.94	1.22
2036	64%	6.25	1.54	9.47	8.00	1.28	66%	8.98	1.44	12.36	10.95	1.22
2037	65%	6.27	1.54	9.47	8.03	1.28	66%	9.01	1.44	12.36	10.97	1.22
2038	65%	6.28	1.54	9.47	8.04	1.28	66%	9.03	1.44	12.36	10.98	1.22
2039	65%	6.29	1.54	9.47	8.06	1.28	66%	9.06	1.44	12.36	11.00	1.21
2040	65%	6.31	1.54	9.47	8.07	**1.28**	66%	9.09	1.44	12.36	11.01	**1.21**
2041	65%	6.32	1.54	9.47	8.08	1.28	66%	9.12	1.44	12.36	11.03	1.21
2042	65%	6.34	1.54	9.47	8.09	1.28	66%	9.14	1.44	12.36	11.04	1.21
2043	65%	6.35	1.54	9.47	8.10	1.27	66%	9.17	1.44	12.36	11.06	1.21
2044	66%	6.37	1.54	9.47	8.11	1.27	66%	9.20	1.44	12.36	11.07	1.20
2045	66%	6.38	1.54	9.47	8.12	1.27	66%	9.23	1.44	12.36	11.09	1.20
2046	66%	6.40	1.54	9.47	8.13	1.27	66%	9.26	1.44	12.36	11.11	1.20
2047	66%	6.41	1.54	9.47	8.14	1.27	66%	9.28	1.44	12.36	11.13	1.20
2048	66%	6.43	1.54	9.47	8.15	1.27	67%	9.31	1.44	12.36	11.14	1.20
2049	66%	6.44	1.54	9.47	8.16	1.27	67%	9.34	1.44	12.36	11.16	1.20
2050	66%	6.45	1.54	9.47	8.18	**1.27**	67%	9.37	1.44	12.36	11.19	**1.19**

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

Specific workbooks used in the modeling system are listed below. **Exhibit 16** 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.

Exhibit 16: Heavy Truck Energy Modeling System Details



1. Heavy Truck Energy Balance Model (HTEBM)-Version 3.0 (Ref. 18).
   - 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 and 8, Type 1 heavy trucks to 2050).
   - TRUCK-2 Type 2 (projects market penetration of Class 7 and 8, Type 2 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, and M results to obtain summary market penetrations and fleet average fuel economies).

3. VISION MODELS
   - VISION 2006 AEO ICE MPG Base Case (projects energy use of baseline truck fleet to 2050).
   - VISION GPRA0 8Veh.Mi-1 (projects energy use of improved truck fleet to 2050).
4. Inputs to NENS and MARKAL for official EERE GRPA benefits estimates. Also, inputs to HvyTrkSum-GPRA-V1 which calculates energy and carbon savings by HT type (which NEMS and MARKAL cannot do) for use by FCVT for their own internal analysis.

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 result from 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. Because 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 this benefits analysis, analysts developed vehicle characteristics to support fuel economy goals in 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 three individual heavy vehicle technologies (accessory loads reduction, engine efficiency increase, and aerodynamic drag reduction). These can be varied to other technologies or Technology Program definitions by the user, if desired.

TRUCK 3.0 Market Penetration Models

The fuel-saving technologies under analysis are characterized in the TRUCK 3.0 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 four years or less. If technology cost information is not available, cost equivalent to a two-year payback is assumed. TRUCK 3.0 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 for each truck type is a projection of market penetration rates (percent of new vehicle sales) by class and type through 2050. 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 because 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.

VISION Models

VISION Base Case Model – The VISION models accept average new fleet MPG values for Class 3-6 and Class 7 and 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 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.

Heavy Truck Summary Model (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 DOE EERE.

HvyTrkSum results form the basis of the benefits of the Heavy Truck program elements.

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