Regulations Requiring Onboard Diagnostic Systems on 2010 and Later Heavy-Duty Engines Used in Highway Vehicles Over 14,000 Pounds; Revisions to Onboard Diagnostic Requirements for Diesel Highway Vehicles Under 14,000 Pounds

Draft Technical Support Document

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Compliance and Innovative Strategies Division
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1. Introduction

This document contains technical details in support of the proposed requirements for onboard diagnostic (OBD) systems on highway applications over 14,000 pounds, and the proposed revisions to existing OBD requirements on highway diesel applications under 14,000 pounds. The details of these proposed requirements are not covered in this document and can be found in the preamble to the proposed regulations contained in the docket for the rule.[1] Comments on the technical details presented in this document are welcomed. Details regarding how to comment on this document can be found in the preamble to the proposed regulations in both the ADDRESSES and SUPPLEMENTARY INFORMATION sections.

The details presented in this document support statements in the technological feasibility and costs sections of the preamble for this rule (sections III and VI, respectively). As such, this document is broken into two sections: technological feasibility and costs. Note that the bulk of our technological feasibility arguments are presented in section III of the preamble. Only the very detailed information behind some of our findings are contained in this technical support document. By contrast, the preamble to the rule contains only a brief summary of our cost estimates while the details behind our cost estimates are presented here.

2. Technological Feasibility

2.1. Update on Oxygen Sensor Development for HD OBD

2.1.1. Current Technology

a. Manufacturers

Zirconium Oxide oxygen sensors have been developed to measure modal O_2 concentration in spark ignition and lean burn engines. There are many manufacturers of these devices.

b. Measurement Principle

There are two typical O_2 sensor designs. The first is the lambda sensor. This sensor consists of a main body that is a U-shaped tube of Zirconia electrolyte. Zirconia is a well known ionic oxygen conductor at high temperatures. Pt electrodes were applied to both sides of the zirconia tube. The inner electrode is open to the atmosphere and the outer side is open to the exhaust gas. An example of the design of a convention lambda sensor can be seen in Figure 1. The electromotive force of the cell is governed by the Nernst equation and can be described as follows:

$$E = \left(\frac{RT}{4F}\right)\ln\left(\frac{P_{O_{2(ref)}}}{P_{O_{2(test)}}}\right)$$

Where R is the ideal gas constant, T is absolute temperature, F is the Faraday constant, $PO_{2(ref)}$ is the partial pressure of the reference gas and $PO_{2(test)}$ is the partial pressure of the sample gas.

The partial pressure of oxygen in the air, $PO_{2(ref)}$ is almost constant and *E* depends on the partial pressure of the exhaust gas, $PO_{2(test)}$. In a lean environment, $PO_{2(test)}$ is close to $PO_{2(ref)}$ and *E* approaches 0V. Under rich conditions, $PO_{2(test)}$ is negligible and *E* approaches 1V. At the stoichiometric point, *E* is about 0.5V. The equilibrium pressure of oxygen abruptly changes near the stoichiometric point and a step change in *E* is evident at this point.[2],[3],[4]

The second type of oxygen sensor design is the UEGO (Universal air to fuel ration Exhaust Gas Oxygen) sensor. The UEGO sensor can detect a wide range of A/F ratios, making it possible to control an engine in a very lean or very rich fuel mixture state. These sensors are usually considered wide range A/F ratio sensors.

The UEGO sensor is amperometric while the lambda sensor is potentiometric. The sensor measures current which is proportional to the partial pressure of oxygen in lean environments and the partial pressure of CO, H_2, and hydrocarbons (C_mH_n) in rich environments. This then provides quantitative information on the A/F ratio. As the A/F ratio increases in a lean environment, excess oxygen in the exhaust increases. As the A/F ratio

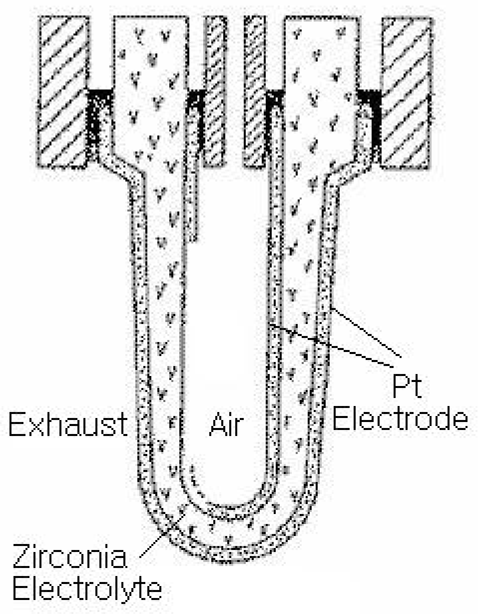

Figure 1. Design of a conventional lambda sensor.

decreases in a rich environment, the partial pressure of CO, H_2 and C_mH_n increases in the exhaust due to oxygen deficiency. The concentration of these gases approach zero at the stoichiometric point with the exhaust being composed of mostly H_2O and CO_2 due to complete combustion.

There are several other types of UEGO sensors, however their basic operating principles are not greatly different. The most common commercial sensor used today is based on zirconia (ZrO_2) partly or fully stabilized with ytteria (Y_2O_3). Figure 2 shows a cross-sectional view of the sensor element. Most sensor designs consist of pumping and potentiometric cells with slight variations in structure. Some sensors have adopted an air-biased pumping cell without the potentiometric cell because it automatically reverses current flow between the rich and lean.[5],[6],[7],[8]

The potentiometric cell decides whether the exhaust is lean or rich and applies the appropriate pumping voltage to the pumping cell depending on the signal. The presence of oxygen vacancies in the material makes the mobility of the oxygen ion O_2^- possible. The resulting conductivity is very low at room temperatures, but reaches values of a wet electrolyte when the sensor is heated up to < 600°C. An oxygen sensor can be constructed if the solid electrolyte is provided with porous electrodes separating two gas chambers. At higher cell temperatures the solid electrolyte conducts oxygen ions, thus an oxygen concentration difference between the two chambers results in a voltage signal. The half cell reactions are as follows:

$$4e^- + O_{2(test)} \rightarrow 2O_2^{2-}$$
$$2O_2^{2-} \rightarrow 4e^- + O_{2(ref)}$$

Just like the lambda sensor, this voltage signal is described in a very good agreement by the Nernst equation:

$$E = \left(\frac{RT}{4F}\right)\ln\left(\frac{P_{O_{2(ref)}}}{P_{O_{2(test)}}}\right)$$

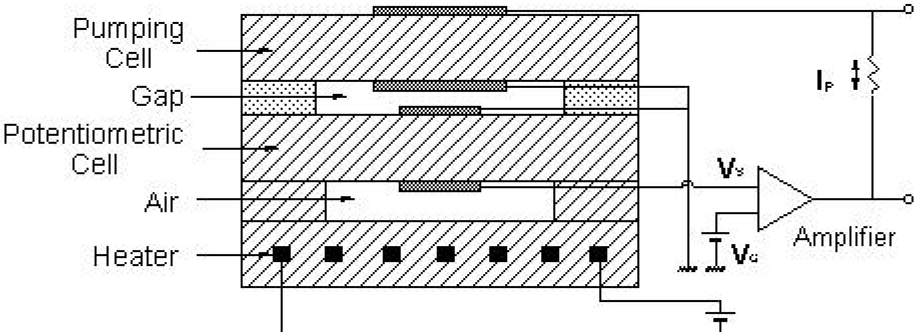

Figure 2. Cross-sectional view of oxygen sensing element.[8]

Each part in the sensing element functions as follows:

By pumping oxygen, the pumping cell controls the partial oxygen pressure in the detecting cavity, which is surrounded by the inner electrode of the pumping cell and the potentiometric cell. The potentiometric cell, made from the oxygen galvanic cell element, works as a conventional oxygen sensor, but without any reference oxygen from atmosphere.

By supplying a very small constant pumping current to the potentiometric cell, oxygen is pumped to the reference oxygen cavity (Air in figure 2) from the detecting cavity, resulting in a constant self-generated oxygen partial pressure in the cavity. The pumping current is controlled by using a feedback circuit to maintain the potentiometric cell voltage.

The pumping cell current is the sensor output and the UEGO sensor shows the pump current respectively proportional to the oxygen amount in the exhaust gas in the lean side and to the oxygen amount required for the complete combustion of combustible gas in the exhaust gas in the rich side. Hence, this value corresponds to the air/fuel ratio.[8]

c. Durability

Durability data for diesel applications is limited. NGK has reported data for 4,700 hours of testing (135,000 mile equivalent) on a 2.5 L diesel engine. This data showed that the aged sensor accuracy was equivalent to the accuracy of the fresh sensor for AFR determination.[9]

These types of sensors have been used in OBD II spark ignition applications for years and have proven to be durable. This durability should transfer directly over to lean burn applications.

APBF-DEC aging to 4,000 hours has been completed and data analysis is in process. Investigation into failure and degradation process is ongoing.[10]

2.1.2. Heavy-duty Air-fuel Ratio (AFR) Measurement for 2010 Technology Engines

a. Usage

It is anticipated that both wide-range AFR sensors and conventional oxygen sensors will be used by the heavy-duty engine manufacturers to optimize their emission control technologies as well as to satisfy many of the proposed heavy-duty OBD monitoring requirements such as, fuel system, catalyst monitoring, and EGR system monitoring. Since these sensors can be a critical component of a vehicle’s fuel and emission control system, the proper performance needs to be assured in order to maintain low emissions. Therefore, any malfunction that adversely affects performance must be detected by the OBD system. This can be achieved through monitoring of the sensor output voltage, resistance, impedance, response rate, and any other characteristic of the oxygen sensor that can effect emissions and/or other diagnostics.

2.2. Update on ZrO2 NOx Sensor Development

2.2.1. Current Technology

a. Manufacturers

Zirconium Oxide NO_x sensors have been developed to measure modal NO_x emissions from lean burn engines. Currently there are three companies that are selling these devices. They are as follows: NGK Automotive Ceramics, Ionotec, and Ceramatec.

b. Measurement Principle

Typical NO_x sensor design consists of two internal cavities and three oxygen pumping cells designed to measure both oxygen (air to fuel ratio measurement) and NO_x concentrations. The most common commercial sensor used today is based on zirconia (ZrO_2) partly or fully stabilized with ytteria (Y_2O_3). The presence of oxygen vacancies in the material makes the mobility of the oxygen ion O_2^- possible. The resulting conductivity is very low at room temperatures, but reaches values of a wet electrolyte when the sensor is heated up to < 600°C. An oxygen sensor can be constructed if the solid electrolyte is provided with porous electrodes separating two gas chambers. At higher cell temperatures the solid electrolyte conducts oxygen ions, thus an oxygen concentration difference between the two chambers results in a voltage signal. The half cell reactions are as follows:

$$4e^- + O_{2(test)} \rightarrow 2O_2^{2-}$$
$$2O_2^{2-} \rightarrow 4e^- + O_{2(ref)}$$

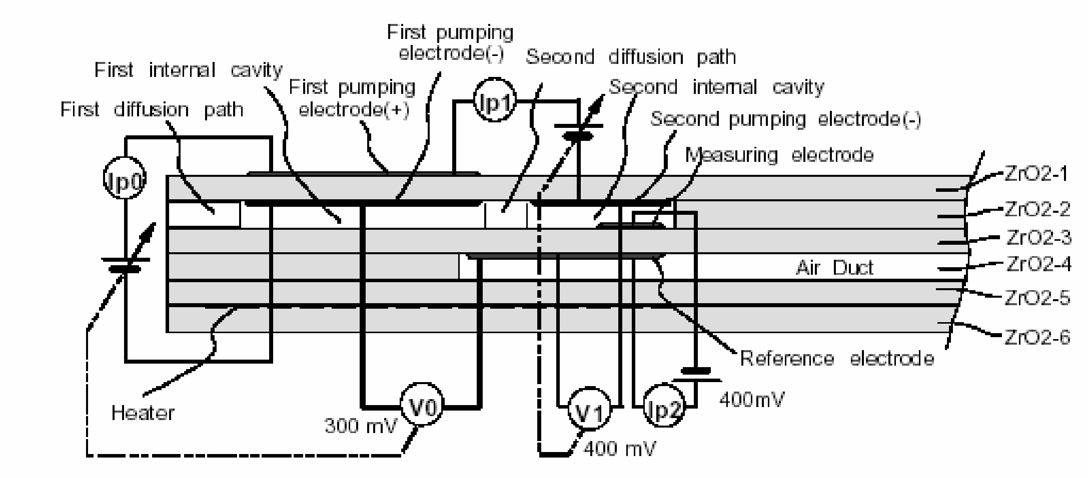

Figure 3. Cross-sectional view of NO_x sensing element.[2]

This voltage signal is described in a very good agreement by the Nernst equation:

$$E = \left(\frac{RT}{4F}\right)\ln\left(\frac{P_{O_{2(ref)}}}{P_{O_{2(test)}}}\right)$$

Where R is the ideal gas constant, T is absolute temperature, F is the Faraday constant, $PO_{2(ref)}$ is the partial pressure of the reference gas and $PO_{2(test)}$ is the partial pressure of the sample gas.

In general, the measurement concept consists of:

1) Lowering the oxygen concentration of a measuring gas to a predetermined level in the first internal cavity, in which NO_x does not decompose, and
2) Further lowering the oxygen concentration of the measuring gas to a predetermined level in the second internal cavity, in which NO_x decomposes on a measuring electrode and the oxygen generated is detected as a sensor signal.

Figure 3 shows a cross-sectional view of the NO_x sensor element. Each part in the sensing element functions as follows:

First Internal Cavity

The first internal cavity connects a measuring gas stream through the first diffusion path under a predetermined diffusion resistance. There is an oxygen pumping cell and an oxygen sensing cell inside the first internal cavity.

The first oxygen pumping cell consists of a pair of first pumping (+) and (-) electrodes on the ZrO_2-1 layer, in order to lower the oxygen concentration to a predetermined level. The first pumping electrode (+) is platinum and the (-) electrode is a platinum/gold alloy to reduce NO_x reduction catalytic activity.

The oxygen sensing cell consists of the first pumping (-) electrode in the first internal cavity and a reference electrode in an air duct. This allows monitoring of the oxygen concentration in the first internal cavity by generated electromotive force and feedback to the first oxygen pumping cell.

Second Internal Cavity

The second internal cavity connects to the first internal cavity through the second diffusion path under a predetermined diffusion resistance. There are two different oxygen pumping cells and an oxygen sensing cell inside the second internal cavity.

The second oxygen pumping cell consists of the second pumping (-) electrode in the second internal cavity and the first pumping (+) electrode on the ZrO_2-1 layer, in order to further lower the oxygen concentration to a predetermined level. The second pumping (-) electrode is also made of a platinum/gold alloy.

The oxygen sensing cell consists of the second pumping (-) electrode and the reference electrode in the air duct to monitor the oxygen concentration in the second internal cavity by generated electromotive force and feedback to the second oxygen pumping cell.

The NO_x sensing cell consists of a measuring electrode in the second internal cavity and the reference electrode in the air duct. The measuring electrode is rhodium and has a NO_x reduction catalytic activity. Therefore, NO_x decomposes on the measuring electrode and the oxygen generated is detected as an oxygen pumping current in the NO_x sensing cell. The sensor signal is in proportion to the NO_x concentration in the measuring gas.[11]

c. Measurement Range

ZrO_2 NO_x sensors are currently available in the 0 – 500 ppm, 0 – 1500 ppm, and 0 – 2000 ppm range. Reported accuracy is in the ± 10% range for readings in the 100 to 2000 ppm range and ± 10 ppm for readings in the 0 to 100 ppm range.

d. Interference

ZrO_2 NO_x sensor interference has been limited to ammonia (NH_3). Sensitivity to NH_3 has been shown to be up to 65% of the amount of NH_3 present in the sample gas. This NH_3 is converted to NO_x in the internal cavities of the sensor and then measured.[12] This phenomenon may only plague urea SCR applications, where over dosing of urea could lead to NH_3 slip. In addition, urea SCR feedback control studies have shown that the NH_3 interference signal is discernable from the NO_x signal and can, in effect, allow the design of a better feedback control loop than a NO_x sensor that doesn't have any NH_3 cross-sensitivity. The signal conditioning method developed, resulted in a linear output for both NH_3 and NO_x from the NO_x sensor downstream of the catalyst.[12]

e. Durability

Durability data for diesel applications is limited. NGK has reported data for 1000 hours of testing (60,000 mile equivalent) on a 2.5 L diesel engine. This data showed that the aged sensor achieved ± 20 ppm (or ± 7% measurement error) NO_x accuracy for a 300 ppm NO_x sample on a 0 to 2000 ppm range sensor. This is almost equivalent to the accuracy of the fresh sensor in this concentration range.[13]

Twenty-five NGK NO_x sensors in the 0 to 2000 ppm range are currently undergoing 6,000 hours of aging on a 12 L Caterpillar C-12 engine. Five of these sensors are in the engine out location, 10 are located downstream of the DPF and upstream of the SCR catalyst, and 10 are located downstream of the clean-up catalyst. NO_x sensors are compared every 1,000 hours and are independently calibrated every 2,000 hours. Currently, data has been reported through 2,000 hours of aging.

Typical sensor NO_x exposure varies by location. On average, the 15 sensors located upstream of the SCR catalyst were exposed to NO_x concentrations in the 100 to 600 ppm range. This is close to the expected range of engine out exhaust emissions for a 2010 engine, but the range maximum is on the low side. The 10 sensors located downstream of the cleanup catalyst were exposed to NO_x concentrations in the 10 to 200 ppm range. Of the pre-catalyst sensors, 12 degraded by 3 to 4%, while the remaining three degraded by 5 to 7%. Of the post-catalyst sensors, 8 had minimal degradation, one failed completely, and one degraded 30%. For those sensors that degraded a similar amount, degradation was linear. Overall relative error ranged from 4% at engine-out concentrations to 12% at lower concentrations.

Aging to 4,000 hours has been completed and data analysis is in process. Investigation into failure and degradation process is ongoing.[14]

2.2.2. Future Improvements

As with any maturing technologies, it is expected that improvements will be made to sensor accuracy and durability in the near future. Requests by engine manufacturers have been made to instrument manufacturers to develop sensors that have improved accuracy in the 0 to 100 ppm range. Instrument manufacturers are complying with these requests and it is expected that NO_x sensors in the 0 to 100 ppm range with ± 5 ppm accuracy will be available by the middle of 2006.

2.2.3. Heavy-duty NOx Detection for 2010 Technology Engines

a. Future NOx Emission Levels

It is expected that NO_x concentrations downstream of an emission control system on an engine meeting the 2010 NO_x standard will be in the 0 to 50 ppm range, on average, depending on engine speed, load, and the state of the emission control system (ECS).

As an example, a 5.9 L Cummins ISB meeting the 2010 NO_x standard for the FTP (0.13 g/hp-hr) and SET (0.12 g/hp-hr) using a NO_x adsorber based ECS will have average NO_x emissions ranging from 0 to 60 ppm.[15] Data from the APBF-DEC Heavy-Duty NO_x Adsorber/DPF Project: Heavy Duty Linehaul Platform reported NO_x emissions downstream of the ECS in the range of 0 to 200 ppm for an engine emitting NO_x in the range of 0.05 to 0.5 g/hp-hr NO_x over 2000 hours.[16] It is important to note that the average NO_x emissions are less than 40 ppm for this engine and ECS. Therefore it is important to note that NO_x spikes larger than the average will have to be dealt with accordingly by the OBD system.

b. Current NOx Sensor Detection Limits

Current NO_x sensors have a stated accuracy of ± 10 ppm in the zero to 100 ppm range for a 0 to 2000 ppm range. Accuracies for some sensors have been reported as high as ± 30 ppm. With this in mind, current NO_x sensor technology should be able detect NO_x emissions that exceed the standard by 2 to 3 times the 2010 limit.

c. Future NOx Sensor Detection Limits

If NO_x sensor manufacturers are able to develop the proposed 0 to 100 ppm range sensor with ± 5 ppm accuracy, it should be possible to accurately measure emissions increases as low as 1.5 times the 2010 NO_x emission standard. With sensor development underway, this sensor should be available by early to mid 2006 for evaluation.

2.3. Fuel Injection Timing Monitor

It should be possible to monitor fuel injection timing by monitoring the crankshaft speed fluctuation and, most notably, the time at which such fluctuation begins, ends, or reaches a peak. The OBD system could compare the time to the commanded fuel injection timing point and verify that the crankcase fluctuation occurred within an acceptable time delay relative to the commanded fuel injection. If the system was working improperly and actual fuel injection was delayed relative to when it was commanded, the corresponding crankshaft speed fluctuation would also be delayed and would result in a longer than acceptable time period between commanded fuel injection timing and crankshaft speed fluctuation.

Such a method has been described as follows in “Controls for Modern Diesel Engines,” found at www.dieselnet.com.

> In fact, some experiments were conducted at the Bendix Diesel Engine Controls in which a signal was obtained and digitized to analyze the impulsive flywheel motion that results from the torque development. Figure 5 shows the results of this experiment which was conducted on a 4-cylinder Volkswagen diesel engine. While the general observation is that in an engine the flywheel is rotating at a steady speed, it is in fact rotating in a pulsating pattern as shown in Figure 5. By referencing the trace in Figure 5, control engineers at Bendix *were able to infer injection timing and fueling for each cylinder*. Analysis of such trace can yield information regarding when the piston began its downward acceleration. From this determination, an injection timing is inferred by referencing the start of piston acceleration to a set top-dead-center reference. Comparative analysis is then conducted by the electronic control unit *to determine the injection timing for each individual cylinder*. In injection systems where individual cylinder control of the fuel injection is available, adjustments can be made to equalize the effective injection timing in all cylinders. *Likewise, the rate and amount of acceleration of each flywheel impulse can be used to infer the fueling in each cylinder*. Once again, the electronic control unit is capable to adjust the cylinder-to-cylinder fueling rate for smoother engine operation…[Emphasis added]

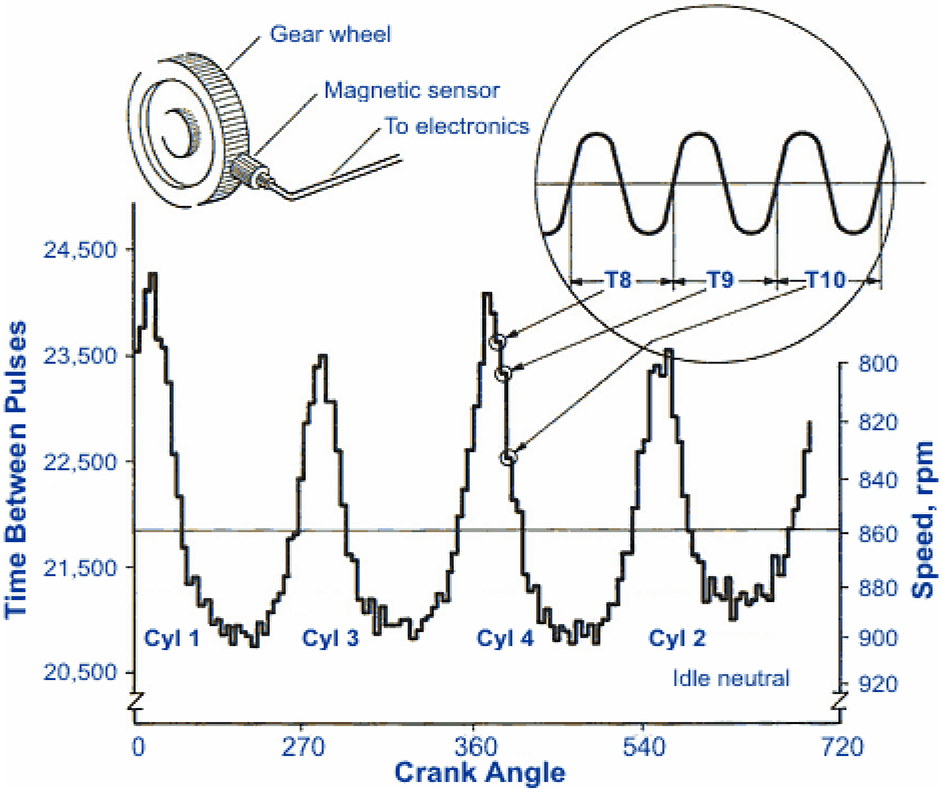

Figure 5. Torque Pulses Development in a 4-Cylinder Diesel Engine

The emphasized text suggests that, in the opinion of the author, such a torque pulse monitor could be used to determine when injection had occurred and, therefore, if injection had occurred at the desired timing. The author also suggests that the technique could be used to determine if the desired fuel quantity had actually been injected. The torque pulses could be determined using the crankshaft position sensor—that exists on the engine for proper engine control absent OBD requirements—that also would be used for engine misfire detection.

3. Costs

This section provides the details behind the cost analysis done in support of our proposed Over14,000 pound OBD program and our proposed changes to the existing Under14,000 pound diesel OBD requirements. Details associated with the proposed requirements and proposed changes to existing requirements can be found in the preamble to the rulemaking and are not presented here. As a result, there may be details within this report that can be understood only by reading the associated preamble for the proposed rulemaking.

This analysis breaks estimated costs into two primary categories: variable costs and fixed costs. Variable costs are those costs associated with any new hardware required to meet the proposed requirements, the associated assembly time to install that hardware, and any increased warranty costs associated with the new hardware. Variable costs are additionally marked up to account for both manufacturer and dealer overhead and carrying costs. The manufacturer's carrying cost was estimated to be four percent of the direct costs to account for the capital cost of the extra inventory and the incremental costs of insurance, handling, and storage. The dealer's carrying cost was estimated to be three percent of their direct costs to account for the cost of capital tied up in inventory. We adopted this same approach to markups in the heavy-duty 2007/2010 rule and our more recent Nonroad Tier 4 rule based on industry input.[17]

Fixed costs considered here are those for research and development (R&D), certification, and production evaluation testing. The fixed costs for engine R&D are estimated to be incurred over the four-year period preceding introduction of the engine. The fixed costs for certification include costs associated with demonstration testing of OBD parent engines including the "limit" parts used to demonstrate detection of malfunctions at or near the applicable OBD thresholds. The demonstration testing costs are estimated to be incurred one year preceding introduction of the engine while the production evaluation testing is estimated to occur in the same year as introduction. Importantly, none of the fixed costs estimated here consider the recent California Air Resources Board approved requirements for over 14,000 pound OBD.[18]

We present all of these costs in the year during which we estimate they will be incurred by manufacturers over the 30 year time period following publication of the final rule. We then calculate a 30 year net present value of those cost streams using both a three percent and a seven percent discount rate to reflect the time value of money at both ends of the most likely range.

We present all costs in 2004 dollars. We refer to both near term costs and long term costs. The near term costs represent those costs when warranty costs are estimated to be the highest. The long term costs consider the effects of a reduction in warranty costs. For warranty costs, we have estimated a three percent near term rate for warranty claims and a one percent long term rate for warranty claims.

3.1. Cost Analysis for Engines Used in Over 14,000 Pound Applications

3.1.1. Variable Costs

The variable costs we have estimated represent those costs associated with various sensors that we believe would have to be added to the engine to provide the required OBD monitoring capability. Our cost estimates are summarized in Table 1.

Table 1. Estimated OBD Hardware Costs for Diesel and Gasoline Engines Used in Vehicles Over 14,000 Pounds

	Diesel	Gasoline
2010-2012 Model Year		
New Hardware		
ECU upgrade	$ 30	$ 10
Purge solenoid for evap leak check	$ -	$ 10
Pressure sensor for evap leak check	$ -	$ 10
Subtotal	$ 30	$ 30
Assembly labor (hours)	0.10	0.30
Assembly labor cost	$ 3	$ 9
Assembly labor overhead at 40%	$ 1	$ 4
Cost to Mfr	$ 34	$ 43
Warranty cost - near term at 3% claim rate	$ 4	$ 4
Mfr. Carrying cost at 4%	$ 1	$ 2
Cost to Buyer - near term	$ 39	$ 48
2013+ Model Year		
New Hardware		
MIL and wiring	$ 10	$ 10
Subtotal (2010+2013)	$ 40	$ 40
Assembly labor (hours)	0.20	0.40
Assembly labor cost	$ 6	$ 12
Assembly labor overhead at 40%	$ 2	$ 5
Cost to Mfr	$ 48	$ 57
Warranty cost - long term at 1% claim rate	$ 2	$ 2
Mfr carrying cost at 4%	$ 2	$ 2
Cost to Buyer - long term	$ 52	$ 61

For the 2010 model year, we believe that both diesel and gasoline engines would have to upgrade their engine control computers, or engine control units, to accommodate the increased computing capacity required for the proposed OBD. We have estimated this cost at $30 per engine for diesel engines and $10 for gasoline engines, inclusive of supplier markup. We have estimated a different cost because we believe that the gasoline engines are using computers similar, if not in fact identical to, their under 14,000 pound counterparts. Therefore, those computer upgrades should cost little, if anything. For diesel engines, we believe that the OBD requirements will result in a more substantial upgrade to existing computers. Also for the 2010 model year, we believe that gasoline engines would have to add both a purge solenoid and a pressure sensor for the evaporative system monitoring requirement. We have estimated the cost of both of these items at $10 a piece inclusive of supplier markup. We believe that the other sensors needed by the OBD system on both diesel and gasoline engines will already be on the engines for either emissions control and/or protection of the engine (e.g., temperature sensors used to protect against condensation formation caused by overcooling of the EGR gases—engine protection—can also be used to monitor the effectiveness of the EGR cooler—OBD). The result is a manufacturer cost subtotal of $30 for both diesel and gasoline engines in the 2010 model year. Note that we have not included costs for a malfunction indicator light (MIL) and associated wiring in the 2010 timeframe since we are not requiring a dedicated MIL until the 2013 model year.

We have estimated that adding these sensors and actuators will require increased assembly time. We have estimated these times at one-tenth of an hour for diesel engines and one-third of an hour for gasoline engines (i.e., six minutes for each newly added part). We have estimated a labor rate of $30 per hour for this assembly along with overhead at 40 percent. This results in an estimated cost to the manufacturer of $34 and $43 for diesel and gasoline engines, respectively, in the 2010 model year.

We have included a warranty cost recovery estimating a three percent warranty claim rate in the near term. We have also included a four percent manufacturer carrying cost to cover increased insurance and inventory costs incurred by the manufacturer.[19] Including these costs results in an end cost to the buyer of roughly $40 and $50 for diesel and gasoline engines, respectively, in the 2010 model year.

For the 2013 model year, we have included costs associated with the dedicated MIL and its wiring. These costs were estimated at $10 per engine inclusive of supplier markup. Following the same process for assembly costs (another one-tenth of an hour per engine), warranty costs (one percent claim rate for the long term), and carrying costs, we have estimated the long term hardware cost to the buyer at roughly $50 and $60 for diesel and gasoline engines, respectively.

To determine the fleetwide estimated hardware costs, or total variable costs, we looked at the projected over 14,000 pound sales data from our 2004 model year certification database which showed projected US sales less projected California sales of 614,500 for diesel engines and 39,400 for gasoline engines. In the 2010 through 2012 model years, we estimated 50 percent of engines would comply with the proposed OBD requirements based on our proposed phase-in schedule. For model years 2013 and later, we will have 100 percent compliance. Applying the estimated hardware costs presented in Table 1 to the appropriate projected sales in each model year through 2035, estimating a two percent growth in sales based on 2004 sales, results in a 30 year net present value (NPV) cost of $620 million and $47 million for diesel and gasoline engines, respectively, using a three percent discount rate. These costs, including a NPV at a seven percent rate, are shown in Table 2.

Table 2. Total OBD Variable Costs for Diesel and Gasoline Engines Used in Vehicles Over 14,000 Pounds

		Diesel				Gasoline				
Year	CY	Projected Sales	$/engine	% complying	Diesel Subtotal	Projected Sales	$/engine	% complying	Gasoline Subtotal	Total
1	2006	639,103	$ -	0%	$ -	40,976	$ -	0%	$ -	$ -
2	2007	651,393	$ -	0%	$ -	41,764	$ -	0%	$ -	$ -
3	2008	663,684	$ -	0%	$ -	42,552	$ -	0%	$ -	$ -
4	2009	675,974	$ -	0%	$ -	43,340	$ -	0%	$ -	$ -
5	2010	688,265	$ 39	50%	$ 13,531,000	44,128	$ 48	50%	$ 1,060,000	$ 14,591,000
6	2011	700,555	$ 39	50%	$ 13,772,000	44,916	$ 48	50%	$ 1,079,000	$ 14,851,000
7	2012	712,846	$ 39	50%	$ 14,014,000	45,704	$ 48	50%	$ 1,098,000	$ 15,112,000
8	2013	725,136	$ 52	100%	$ 37,588,000	46,492	$ 61	100%	$ 2,816,000	$ 40,404,000
9	2014	737,426	$ 52	100%	$ 38,225,000	47,280	$ 61	100%	$ 2,864,000	$ 41,089,000
10	2015	749,717	$ 52	100%	$ 38,862,000	48,068	$ 61	100%	$ 2,912,000	$ 41,774,000
11	2016	762,007	$ 52	100%	$ 39,499,000	48,856	$ 61	100%	$ 2,959,000	$ 42,458,000
12	2017	774,298	$ 52	100%	$ 40,136,000	49,644	$ 61	100%	$ 3,007,000	$ 43,143,000
13	2018	786,588	$ 52	100%	$ 40,774,000	50,432	$ 61	100%	$ 3,055,000	$ 43,829,000
14	2019	798,879	$ 52	100%	$ 41,411,000	51,220	$ 61	100%	$ 3,102,000	$ 44,513,000
15	2020	811,169	$ 52	100%	$ 42,048,000	52,008	$ 61	100%	$ 3,150,000	$ 45,198,000
16	2021	823,459	$ 52	100%	$ 42,685,000	52,796	$ 61	100%	$ 3,198,000	$ 45,883,000
17	2022	835,750	$ 52	100%	$ 43,322,000	53,584	$ 61	100%	$ 3,246,000	$ 46,568,000
18	2023	848,040	$ 52	100%	$ 43,959,000	54,372	$ 61	100%	$ 3,293,000	$ 47,252,000
19	2024	860,331	$ 52	100%	$ 44,596,000	55,160	$ 61	100%	$ 3,341,000	$ 47,937,000
20	2025	872,621	$ 52	100%	$ 45,233,000	55,948	$ 61	100%	$ 3,389,000	$ 48,622,000
21	2026	884,912	$ 52	100%	$ 45,870,000	56,736	$ 61	100%	$ 3,437,000	$ 49,307,000
22	2027	897,202	$ 52	100%	$ 46,507,000	57,524	$ 61	100%	$ 3,484,000	$ 49,991,000
23	2028	909,493	$ 52	100%	$ 47,144,000	58,312	$ 61	100%	$ 3,532,000	$ 50,676,000
24	2029	921,783	$ 52	100%	$ 47,782,000	59,100	$ 61	100%	$ 3,580,000	$ 51,362,000
25	2030	934,073	$ 52	100%	$ 48,419,000	59,888	$ 61	100%	$ 3,628,000	$ 52,047,000
26	2031	946,364	$ 52	100%	$ 49,056,000	60,676	$ 61	100%	$ 3,675,000	$ 52,731,000
27	2032	958,654	$ 52	100%	$ 49,693,000	61,464	$ 61	100%	$ 3,723,000	$ 53,416,000
28	2033	970,945	$ 52	100%	$ 50,330,000	62,252	$ 61	100%	$ 3,771,000	$ 54,101,000
29	2034	983,235	$ 52	100%	$ 50,967,000	63,040	$ 61	100%	$ 3,818,000	$ 54,785,000
30	2035	995,526	$ 52	100%	$ 51,604,000	63,828	$ 61	100%	$ 3,866,000	$ 55,470,000
NPV @	3%				$ 619,863,000				$ 46,559,000	$ 666,422,000
NPV @	7%				$ 327,800,000				$ 24,653,000	$ 352,453,000

3.1.2. Fixed Costs

We have estimated fixed costs for research and development (R&D), certification, and production evaluation testing. The R&D costs include the costs to develop the computer algorithms required to diagnose engine and emission control systems, and the costs for applying the developed algorithms to each engine family and to each variant within each engine family. The certification costs include the costs associated with testing of durability data vehicles (i.e., the OBD parent engines), the costs associated with generating the "limit" parts that are required to demonstrate OBD detection at or near the applicable emissions thresholds, and the costs associated with generating the necessary certification documentation. Production evaluation testing costs consist of the costs associated with the three different elements of production evaluation testing.

a. Research & Development Costs

We have broken the estimated R&D costs into three separate categories. The first of these is the cost for developing computer controlled diagnostic algorithms. These costs are estimated to be incurred once per manufacturer since once an algorithm is developed, it can, practically speaking, be used over and over again with only minor changes, if any, to improve upon the original. The second R&D cost is that for applying the manufacturer's developed algorithm to each of its engine families. Each engine family may have a different number of cylinders or different emissions control architecture (e.g., different combinations of aftertreatment devices) and the algorithm may have to be adapted for each of these engine families. Consequently, this cost is estimated to be incurred once for each of the engine families expected to be sold. The third R&D cost is that for applying the algorithm that has been adapted for each engine family to every variant within each engine family. Variants within engine families have different horsepower and/or torque characteristics and, therefore, the adapted algorithm would have to be fine tuned to each of the engine family's variants. These costs are estimated to be incurred once for each of the remaining variants within each family (i.e., one variant will use the adapted algorithm while the remaining variants will require further fine tuning).

We have estimated separate development and separate application costs for the different types of monitors—system monitors, rationality monitors, and comprehensive component monitors. System monitors are generally the most difficult monitors and for the most part are those monitors for which an emissions threshold exists. Nonetheless, most system monitors are not correlated to an emissions threshold and are, instead, functional monitors that can detect a malfunctioning component prior to emissions exceeding the applicable thresholds. For such monitors, manufacturers generally forego the more costly emissions correlation work and rely on the functional check alone which saves both time and money.

We have estimated that an engineer and a technician would be involved in most of the development work since much of the work will entail testing on an engine test bed. We have estimated that an engineer costs $100,000 a year while a technician costs $60,000 a year, and that they each work 48 forty hour weeks per year. Table 3 shows these R&D costs for diesel engines. The total costs shown represent industry totals for ten manufacturers.

Table 3. R&D Costs for OBD Algorithm Development and Application – Diesel Engines for Over 14,000 Pound Applications

A. Algorithm Development Costs	weeks/monitor	Cost/monitor	# of monitors	Total/Mfr	Total
System Threshold Monitors					
Engineer $	30	$ 63,000			
Technician $	15	$ 19,000			
Subtotal		$ 82,000	13	$ 1,066,000	$ 10,660,000
System Functional Monitors					
Engineer $	20	$ 42,000			
Technician $	5	$ 6,000			
Subtotal		$ 48,000	37	$ 1,776,000	$ 17,760,000
CCM Rationality Monitors					
Engineer $	15	$ 31,000			
Technician $	1	$ 1,000			
Subtotal		$ 32,000	50	$ 1,600,000	$ 16,000,000
CCM Continuity Monitors					
Engineer $	2	$ 4,000			
Technician $	-	$ -			
Subtotal		$ 4,000	80	$ 320,000	$ 3,200,000
Total				$ 4,762,000	$ 47,620,000

B. Application Costs to each Family	weeks/monitor	Cost/monitor	# of monitors	Total/Family	# families/mfr	Total/Mfr	Total
System Threshold Monitors							
Engineer $	5	$ 10,000					
Technician $	10	$ 13,000					
Subtotal		$ 23,000	13	$ 299,000	6.5	$ 1,944,000	$ 19,440,000
System Functional Monitors							
Engineer $	5	$ 10,000					
Technician $	10	$ 13,000					
Subtotal		$ 23,000	37	$ 851,000	6.5	$ 5,532,000	$ 55,320,000
CCM Rationality Monitors							
Engineer $	3	$ 6,000					
Technician $	1	$ 1,000					
Subtotal		$ 7,000	50	$ 350,000	6.5	$ 2,275,000	$ 22,750,000
Total				$ 1,500,000		$ 9,751,000	$ 97,510,000

C. Application Costs to remaining Variants			Total/Variant	# variants/family	# families/mfr	Total/Mfr	Total
Total			$ 375,000	4	6.5	$ 9,750,000	$ 97,500,000

For diesel engines, using industry input and our own engineering analysis, we have estimated that there will be roughly 50 system monitors. Of these, we treated 13 as threshold monitors with the remainders being functional monitors.[a] Based on industry input, we have also estimated that there will be an additional 50 rationality monitors and 80 circuit continuity monitors.

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[a] The 13 threshold monitors for diesel engines, based on our engineering judgment, would be: fuel system pressure high; fuel system injection timing too advanced; fuel system injection timing too retarded; EGR low flow; EGR slow response; EGR low cooling; variable valve timing (VVT) above target; VVT below target; VVT slow response; NMHC catalyst conversion; NOx catalyst system conversion; NOx catalyst system reductant delivery; NOx adsorber performance; DPF filtering performance; DFP NMHC conversion; NOx sensor slow response; and, NOx sensor offset. We have estimated 50 percent of engines to be SCR equipped with 50 percent being NOx adsorber equipped. Similarly, we have estimated 50 percent to be EGR equipped with 50 percent being VVT equipped. Using these factors on the list of threshold monitors results in 12.5 monitors for the "average" diesel engine which we have rounded to 13.

We believe that algorithm development will be more resource intensive than will algorithm application (on a per monitor basis). For algorithm development of system threshold monitors, we have estimated 30 engineer-weeks of development per monitor and 15 technician-weeks per monitor while for system functional monitors we have estimated 20 and 5 weeks of development per monitor, respectively. For rationality monitors, we have estimated 15 engineer-weeks and only one technician-week since determining the proper rationality—the engineer's job—can be difficult but testing and verifying that it works—the technician's job—should not be difficult. For circuit continuity monitors, we have estimated only two engineer-weeks and no technician weeks since these monitors are relatively straight forward (open circuit/short circuit).

Multiplying by the engineer and technician labor rates and the number of monitors results in total costs of $48 million which will be incurred during the four year period leading up to implementation (i.e., during the years 2006 through 2009). These costs are shown in Table 3A.

For algorithm application to each engine family, we have estimated that the majority of the work will entail testing and, therefore, it will be done by the technician. For system threshold monitors and functional monitors, we have estimated five engineer-weeks and 10 technician weeks. For rationality monitors, we have estimated three engineer-weeks and one technician-week because adapting these algorithms should be more straight forward than adapting system monitors. For circuit continuity monitors, we have estimated no costs for applying algorithms since these should be directly applicable to any engine.

These algorithm application costs will be incurred on each engine family. Our 2004 model year database shows a total of 65 diesel engine families meant for over 14,000 pound vehicles. The database also shows 10 heavy-duty diesel engine manufacturers for an average of 6.5 engine families per manufacturer. Multiplying the estimated weeks by the appropriate engineering and technician labor rates, the number of monitors, the number of engine families per manufacturer, and the number of manufacturers results in total costs of $98 million dollars. These costs are shown in Table 3B. These costs will be incurred on some engine families during the four years leading up to the 2010 model year (i.e., one engine family per manufacturer) and on the remaining families during the four years leading up to the 2013 model year.

To estimate the costs for fine tuning the adapted algorithm to the remaining variants within each engine family, we have considered this to take roughly one-quarter the effort required for the initial engine family application. Therefore, the $375,000 cost per variant is estimated as one-quarter of the $1.5 million per family cost to apply the algorithm to the engine family. The variant based application costs are estimated to be incurred by those remaining variants within the engine family (i.e., these costs are not incurred on the variant for which the initial application work was done). Based on input from industry, we have estimated that there is an average of five variants per engine family. As a result, the variant application cost will be incurred on four variants per engine family. Multiplying the cost per variant by the number of remaining variants, the average number of engine families per manufacturer and again by the number of manufacturers results in another $98 million dollars in total costs. These costs are shown in Table 3C. These costs will be incurred on some engine families during the four years leading up to the 2010 model year (i.e., four variants within one engine family per manufacturer) and on the variants of the remaining families during the four years leading up to the 2013 model year.

We have used this same process for estimating the R&D costs for gasoline engines which are shown in Table 4. We have used many of the same estimates for gasoline engines as for diesel engines with the exception that we have estimated only eight system threshold monitors for gasoline engines.[b] As shown in Table 4A, we have estimated that the algorithm development costs for gasoline engines will be zero since the manufacturers of gasoline engines (only Ford and General Motors have certified gasoline engines for over 14,000 pound vehicles) have been complying with OBD requirements for over 10 years on their under 14,000 pound vehicles. We believe that the algorithms used in under 14,000 pound vehicles will be directly applicable to over 14,000 pound vehicles with only some adapting of those algorithms. The costs for adapting the existing algorithms to each engine family are shown in Table 4B where we have estimated the costs at $4.5 million. Note that our 2004 model year certification database shows two over 14,000 pound engine families certified by General Motors and none certified by Ford. We have estimated that Ford will certify an engine family in future model years and, therefore, have estimated an average of 1.5 engine families per manufacturer. Table 4C shows the costs for applying algorithms to each remaining variant within the engine family. Again, we have estimated this cost at one-quarter the cost of first adapting an algorithm to the engine family. These efforts are estimated to result in another $4.5 million. All of these gasoline engine costs will be incurred in a manner analogous to that described above for diesel engines.

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[b] The eight threshold monitors for gasoline engines, based on our engineering judgement, would be: fuel system too rich; fuel system too lean; multiple cylinder random misfire; secondary air system low flow; catalyst conversion; EGR low flow; variable valve timing (VVT) above target; VVT below target; VVT slow response; and primary exhaust gas sensor slow response. As with diesel engines, we have estimated 50 percent to be EGR equipped with 50 percent being VVT equipped.

Table 4. R&D Costs for OBD Algorithm Development and Application – Gasoline Engines for Over 14,000 Pound Applications

A. Algorithm Development Costs	weeks/monitor	Cost/monitor	# of monitors	Total/Mfr	Total
System Threshold Monitors					
Engineer $	30	$ 63,000			
Technician $	15	$ 19,000			
Subtotal		$ 82,000	-	$ -	$ -
System Functional Monitors					
Engineer $	20	$ 42,000			
Technician $	5	$ 6,000			
Subtotal		$ 48,000	-	$ -	$ -
CCM Rationality Monitors					
Engineer $	15	$ 31,000			
Technician $	1	$ 1,000			
Subtotal		$ 32,000	-	$ -	$ -
CCM Continuity Monitors					
Engineer $	2	$ 4,000			
Technician $	-	$ -			
Subtotal		$ 4,000	-	$ -	$ -
Total				$ -	$ -

B. Application Costs to each Family	weeks/monitor	Cost/monitor	# of monitors	Total/Family	# families/mfr	Total/Mfr	Total
System Threshold Monitors							
Engineer $	5	$ 10,000					
Technician $	10	$ 13,000					
Subtotal		$ 23,000	8	$ 184,000	1.5	$ 276,000	$ 552,000
System Functional Monitors							
Engineer $	5	$ 10,000					
Technician $	10	$ 13,000					
Subtotal		$ 23,000	42	$ 966,000	1.5	$ 1,449,000	$ 2,898,000
CCM Rationality Monitors							
Engineer $	3	$ 6,000					
Technician $	1	$ 1,000					
Subtotal		$ 7,000	50	$ 350,000	1.5	$ 525,000	$ 1,050,000
Total				$ 1,500,000		$ 2,250,000	$ 4,500,000

C. Application Costs to remaining Variants			Total/Variant	# variants/family	# families/mfr	Total/Mfr	Total
Total			$ 375,000	4	1.5	$ 2,250,000	$ 4,500,000

Closely associated with the costs shown in Table 3 and Table 4 would be costs associated with operating and maintaining the test cells required for testing and evaluating the OBD systems and associated algorithms. To determine these costs we projected that two types of test cell work would be done. The first would be actual emissions testing using a certified emissions test cell. The other would be performance and/or endurance testing done in a development test cell where OBD monitors could be evaluated against functional criteria rather than emissions criteria and where operating hours can be amassed far more cost efficiently than by using a certified emissions test cell. The costs associated with these different test cells were estimated at $700 per hour for an emissions test cell and $100 per hour for an endurance test cell. We also estimated that 90 percent of the test cell time for OBD development work would be done in an endurance test cell with the remaining 10 percent being done in an emissions test cell.

Table 5 shows the test cell costs we have estimated for diesel engines. Note that these costs represent the costs associated with operating existing test cells for the sake of meeting the proposed OBD requirements. We are not projecting that any new test cells would have to be built. As shown in Table 5, we have estimated the test cell demand for algorithm development of a system threshold monitor at three weeks. Algorithm development of a system functional monitor was estimated to require two weeks of test cell time while a rationality monitor was estimated at one week. We have estimated no test cell demand for circuit continuity monitors. We have used the same base estimates for the test cell demand associated with applying algorithms to individual engine families except that we have estimated the demand to be only 30 percent of that required for algorithm development. The same is true for applying engine family algorithms to individual variants except here we have estimated the demand to be only 10 percent of that required for initial algorithm development.

Table 5 shows how these costs are incurred in preparation for compliance in the 2010 model year and the 2013 model year. As stated above, 90 percent of the test cell demand—i.e., the total test weeks—would be met using an endurance test cell at $100 per hour while the remaining 10 percent of the demand would be met using an emissions test cell at $700 per hour. Note that there would be no test cell demand for algorithm development beyond that incurred for 2010 since the same algorithms would be used for 2010 and later model years. Table 5A shows an estimated cost for test cell operation of $1.8 million per manufacturer or $18 million for the industry in preparation for the 2010 model year. These costs would be incurred over the four year period leading up to the 2010 model year. For the 2013 model year when 100 percent compliance is required, the cost is estimated at $4 million per manufacturer or $40 million total to be spread over the four year period leading up to the 2013 model year. The 2013 costs are shown in Table 5B.

Table 6A and Table 6B show the analogous information for gasoline engines complying in the 2010 and 2013 model years, respectively. The table shows that we have estimated no costs—development or test cell—for developing monitoring algorithms for gasoline engines since the same algorithms as are used on under 14,000 pound vehicles can be used for over 14,000 pound vehicles. The test cell costs for gasoline engines are estimated at $1.4 million for 2010 model year compliance and $700 thousand for 2013 model year compliance. As with the diesel costs, these costs are expected to be incurred over the four year period leading up to the first year of compliance.

Table 7 and Table 8 summarize the estimated test cell demand per manufacturer for meeting the 2010 and the 2013 requirements. These summaries estimate that testing is conducted during 48 weeks in a given year.

Table 5. OBD R&D Test Cell Costs – Diesel Engines for Over 14,000 Pound Applications

A. R&D Test Cell Costs - Diesel	Cost for 2010							
Monitor Algorithms	test wks	# of monitors			total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	3	13			39.0	$ 250,000	10	$ 2,500,000
System monitor - functional	2	37			74.0	$ 474,000	10	$ 4,740,000
Rationality monitor	1	50			50.0	$ 320,000	10	$ 3,200,000
Subtotal						$ 1,044,000		$ 10,440,000
$ per year for 4 years						$ 261,000		$ 2,610,000
Monitor Application to each engine family								
factor	30%	# of monitors	# families/mfr		total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.9	13	1.0		11.7	$ 75,000	10	$ 750,000
System monitor - functional	0.6	37	1.0		22.2	$ 142,000	10	$ 1,420,000
Rationality monitor	0.3	50	1.0		15.0	$ 96,000	10	$ 960,000
Subtotal						$ 313,000		$ 3,130,000
$ per year for 4 years						$ 78,250		$ 782,500
Monitor Application to each engine family variant								
factor	10%	# of monitors	# families/mfr	additional variants	total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.3	13	1.0	4.0	15.6	$ 100,000	10	$ 1,000,000
System monitor - functional	0.2	37	1.0	4.0	29.6	$ 189,000	10	$ 1,890,000
Rationality monitor	0.1	50	1.0	4.0	20.0	$ 128,000	10	$ 1,280,000
Subtotal						$ 417,000		$ 4,170,000
$ per year for 4 years						$ 104,250		$ 1,042,500
Total R&D Test Cell Costs						**$ 1,774,000**		**$ 17,740,000**
$ per year for 4 years						**$ 443,500**		**$ 4,435,000**

B. R&D Test Cell Costs - Diesel	Costs for 2013							
Monitor Algorithms	test wks	# of monitors			total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	3	-			-	$ -	10	$ -
System monitor - functional	2	-			-	$ -	10	$ -
Rationality monitor	1	-			-	$ -	10	$ -
Subtotal						$ -		$ -
$ per year for 4 years						$ -		$ -
Monitor Application to each engine family								
factor	30%	# of monitors	# families/mfr		total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.9	13	5.5		64.4	$ 412,000	10	$ 4,120,000
System monitor - functional	0.6	37	5.5		122.1	$ 781,000	10	$ 7,810,000
Rationality monitor	0.3	50	5.5		82.5	$ 528,000	10	$ 5,280,000
Subtotal						$ 1,721,000		$ 17,210,000
$ per year for 4 years						$ 430,250		$ 4,302,500
Monitor Application to each engine family variant								
factor	10%	# of monitors	# families/mfr	additional variants	total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.3	13	5.5	4.0	85.8	$ 549,000	10	$ 5,490,000
System monitor - functional	0.2	37	5.5	4.0	162.8	$ 1,042,000	10	$ 10,420,000
Rationality monitor	0.1	50	5.5	4.0	110.0	$ 704,000	10	$ 7,040,000
Subtotal						$ 2,295,000		$ 22,950,000
$ per year for 4 years								
Total R&D Test Cell Costs						**$ 4,016,000**		**$ 40,160,000**
$ per year for 4 years						**$ 1,004,000**		**$ 10,040,000**

Table 6. OBD R&D Test Cell Costs – Gasoline Engines for Over 14,000 Pound Applications

A. R&D Test Cell Costs - Gasoline	Cost for 2010							
Monitor Algorithms	test wks	# of monitors			total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	3	-			-	$ -	2	$ -
System monitor - functional	2	-			-	$ -	2	$ -
Rationality monitor	1	-			-	$ -	2	$ -
Subtotal						$ -		$ -
$ per year for 4 years						$ -		$ -
Monitor Application to each engine family								
factor	30%	# of monitors	# families/mfr		total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.9	8	1.0		7.2	$ 46,000	2	$ 92,000
System monitor - functional	0.6	42	1.0		25.2	$ 161,000	2	$ 322,000
Rationality monitor	0.3	50	1.0		15.0	$ 96,000	2	$ 192,000
Subtotal						$ 303,000		$ 606,000
$ per year for 4 years						$ 75,750		$ 151,500
Monitor Application to each engine family variant								
factor	10%	# of monitors	# families/mfr	additional variants	total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.3	8	1.0	4.0	9.6	$ 61,000	2	$ 122,000
System monitor - functional	0.2	42	1.0	4.0	33.6	$ 215,000	2	$ 430,000
Rationality monitor	0.1	50	1.0	4.0	20.0	$ 128,000	2	$ 256,000
Subtotal						$ 404,000		$ 808,000
$ per year for 4 years						$ 101,000		$ 202,000
Total R&D Test Cell Costs						**$ 707,000**		**$ 1,414,000**
$ per year for 4 years						**$ 176,750**		**$ 353,500**

B. R&D Test Cell Costs - Gasoline	Costs for 2013							
Monitor Algorithms	test wks	# of monitors			total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	3	-			-	$ -	2	$ -
System monitor - functional	2	-			-	$ -	2	$ -
Rationality monitor	1	-			-	$ -	2	$ -
Subtotal						$ -		$ -
$ per year for 4 years						$ -		$ -
Monitor Application to each engine family								
factor	30%	# of monitors	# families/mfr		total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.9	8	0.5		3.6	$ 23,000	2	$ 46,000
System monitor - functional	0.6	42	0.5		12.6	$ 81,000	2	$ 162,000
Rationality monitor	0.3	50	0.5		7.5	$ 48,000	2	$ 96,000
Subtotal						$ 152,000		$ 304,000
$ per year for 4 years						$ 38,000		$ 76,000
Monitor Application to each engine family variant								
factor	10%	# of monitors	# families/mfr	additional variants	total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.3	8	0.5	4.0	4.8	$ 31,000	2	$ 62,000
System monitor - functional	0.2	42	0.5	4.0	16.8	$ 108,000	2	$ 216,000
Rationality monitor	0.1	50	0.5	4.0	10.0	$ 64,000	2	$ 128,000
Subtotal						$ 203,000		$ 406,000
$ per year for 4 years						$ 50,750		$ 101,500
Total R&D Test Cell Costs						**$ 355,000**		**$ 710,000**
$ per year for 4 years						**$ 88,750**		**$ 177,500**

Table 7. OBD R&D Test Cell Demand per Manufacturer – Diesel Engines for Over 14,000 Pound Applications

A. R&D Test Cell Demand - Diesel	For 2010		
	Total test wks	CVS cell test wks	Endurance cell test wks
Monitor Algorithms	163.0	16.3	146.7
Monitor Application to each engine family	48.9	4.9	44.0
Monitor Application to each engine family variant	65.2	6.5	58.7
Total	277.1	27.7	249.4
Cells needed per mfr		0.6	5.2
Cells needed per mfr per each of 4 years		0.1	1.3

B. R&D Test Cell Demand - Diesel	For 2013		
	Total test wks	CVS cell test wks	Endurance cell test wks
Monitor Algorithms	-	-	-
Monitor Application to each engine family	269.0	26.9	242.1
Monitor Application to each engine family variant	358.6	35.9	322.7
Total	627.6	62.8	564.8
Cells needed per mfr		1.3	11.8
Cells needed per mfr per each of 4 years		0.3	2.9

Table 8. OBD R&D Test Cell Demand per Manufacturer – Gasoline Engines for Over 14,000 Pound Applications

A. R&D Test Cell Demand - Gasoline	For 2010		
	Total test wks	CVS cell test wks	Endurance cell test wks
Monitor Algorithms	-	-	-
Monitor Application to each engine family	47.4	4.7	42.7
Monitor Application to each engine family variant	63.2	6.3	56.9
Total	110.6	11.1	99.5
Cells needed per mfr		0.2	2.1
Cells needed per mfr per each of 4 years		0.1	0.5

B. R&D Test Cell Demand - Gasoline	For 2013		
	Total test wks	CVS cell test wks	Endurance cell test wks
Monitor Algorithms	-	-	-
Monitor Application to each engine family	23.7	2.4	21.3
Monitor Application to each engine family variant	31.6	3.2	28.4
Total	55.3	5.5	49.8
Cells needed per mfr		0.1	1.0
Cells needed per mfr per each of 4 years		0.0	0.3

These R&D costs—algorithm development, algorithm application, and test cell—are summarized in Table 9 for both diesel and gasoline engines. The net present value of the estimated R&D costs through 2035 is $273 million using a three percent discount rate.

Table 9. Summary of OBD R&D Costs – Diesel and Gasoline Engines for Over 14,000 Pound Applications

		Diesel				Gasoline				
Year	CY	R&D-Algorithms	R&D-Application	R&D-Test Cell	Subtotal R&D	R&D-Algorithms	R&D-Application	R&D-Test Cell	Subtotal R&D	Total R&D
1	2006	$ 11,905,000	$ 7,500,000	$ 4,435,000	$ 23,840,000	$ -	$ 1,500,000	$ 354,000	$ 1,854,000	$ 25,694,000
2	2007	$ 11,905,000	$ 7,500,000	$ 4,435,000	$ 23,840,000	$ -	$ 1,500,000	$ 354,000	$ 1,854,000	$ 25,694,000
3	2008	$ 11,905,000	$ 7,500,000	$ 4,435,000	$ 23,840,000	$ -	$ 1,500,000	$ 354,000	$ 1,854,000	$ 25,694,000
4	2009	$ 11,905,000	$ 48,750,000	$ 14,475,000	$ 75,130,000	$ -	$ 2,250,000	$ 532,000	$ 2,782,000	$ 77,912,000
5	2010	$ -	$ 41,250,000	$ 10,040,000	$ 51,290,000	$ -	$ 750,000	$ 178,000	$ 928,000	$ 52,218,000
6	2011	$ -	$ 41,250,000	$ 10,040,000	$ 51,290,000	$ -	$ 750,000	$ 178,000	$ 928,000	$ 52,218,000
7	2012	$ -	$ 41,250,000	$ 10,040,000	$ 51,290,000	$ -	$ 750,000	$ 178,000	$ 928,000	$ 52,218,000
8	2013	$ -	$ -	$ -	$ -	$ -			$ -	$ -
9	2014	$ -	$ -	$ -	$ -	$ -			$ -	$ -
10	2015	$ -	$ -	$ -	$ -	$ -			$ -	$ -
11	2016	$ -	$ -	$ -	$ -	$ -			$ -	$ -
12	2017	$ -	$ -	$ -	$ -	$ -			$ -	$ -
13	2018	$ -	$ -	$ -	$ -	$ -			$ -	$ -
14	2019	$ -	$ -	$ -	$ -	$ -			$ -	$ -
15	2020	$ -	$ -	$ -	$ -	$ -			$ -	$ -
16	2021	$ -	$ -	$ -	$ -	$ -			$ -	$ -
17	2022	$ -	$ -	$ -	$ -	$ -			$ -	$ -
18	2023	$ -	$ -	$ -	$ -	$ -			$ -	$ -
19	2024	$ -	$ -	$ -	$ -	$ -			$ -	$ -
20	2025	$ -	$ -	$ -	$ -	$ -			$ -	$ -
21	2026	$ -	$ -	$ -	$ -	$ -			$ -	$ -
22	2027	$ -	$ -	$ -	$ -	$ -			$ -	$ -
23	2028	$ -	$ -	$ -	$ -	$ -			$ -	$ -
24	2029	$ -	$ -	$ -	$ -	$ -			$ -	$ -
25	2030	$ -	$ -	$ -	$ -	$ -			$ -	$ -
26	2031	$ -	$ -	$ -	$ -	$ -			$ -	$ -
27	2032	$ -	$ -	$ -	$ -	$ -			$ -	$ -
28	2033	$ -	$ -	$ -	$ -	$ -			$ -	$ -
29	2034	$ -	$ -	$ -	$ -	$ -			$ -	$ -
30	2035	$ -	$ -	$ -	$ -	$ -			$ -	$ -
NPV @	3%	$ 44,252,000	$ 168,197,000	$ 50,638,000	$ 263,087,000	$ -	$ 8,127,000	$ 1,921,000	$ 10,048,000	$ 273,136,000
NPV @	7%	$ 40,325,000	$ 139,459,000	$ 42,783,000	$ 222,567,000	$ -	$ 7,155,000	$ 1,691,000	$ 8,846,000	$ 231,412,000

b. Certification and Production Evaluation Testing Costs

As noted above, the certification costs include the costs associated with testing of durability data vehicles (i.e., the OBD parent engines), the costs associated with generating the “limit” parts that are required to demonstrate OBD detection at or near the applicable emissions thresholds, and the costs associated with generating the necessary certification documentation.

Cost of OBD Limit Parts

We look first at the costs associated with generating limit parts for certification demonstration testing. These are the parts used to demonstrate OBD detection at or near the applicable emissions thresholds. Such parts can be very difficult to generate because of the difficulties associated with deteriorating parts just the right amount—not so much that the thresholds are grossly exceeded thereby making the demonstration test somewhat meaningless and not so little that emissions remain well below the thresholds.

Table 10 shows the costs we have estimated for the limit parts needed for diesel engine demonstration testing. To arrive at these costs, we estimated the part costs of aftertreatment devices based on our 2007/2010 highway heavy-duty rule and our recent nonroad Tier 4 rule. However, since those costs represented costs of new parts being mass produced, we doubled the costs here to represent the higher costs associated with orders to suppliers consisting of only one or two parts. Fuel system costs were estimated to include costs for injectors, pressure regulators, etc. The exhaust gas sensor costs estimate NOx sensors and estimate that these are ordered (and costed) in sets of two. We estimated the costs for a typical light-heavy, medium-heavy, and heavy-heavy engine assuming 6, 8, and 14 liter displacements, respectively. We sales weighted these costs using the projected sales data from our 2004 model year certification database excluding California sales and excluding those engines certified for use in vehicles under 14,000 pounds. We have estimated that two parts would be needed to account for possible errors and/or the need for parts to demonstrate both a high and a low failure (e.g., EGR flow high/EGR flow low). For variable valve timing (VVT) costs, we have estimated these based on input from industry and not based on our prior analyses which did not consider costs for VVT systems. As shown in Table 10, multiplying through and including the percent of engines we expect will need the particular limit parts, results in limit parts cost of $19,400 for each diesel engine undergoing demonstration testing.

Table 10. Cost for OBD Certification Demonstration Limit Parts – Diesel Engines for Over 14,000 Pound Applications

Diesel Engines	Light-heavy 14-19.5K	Medium-heavy	Heavy-heavy	Sales Weighted	Parts needed (incl errors)	Percent needing part	Fleet weighted
Displacement	6	8	14				
2004 Projected Sales less CA sales	21,695	361,393	231,434	614,522			
NOx Adsorber	$ 1,500	$ 2,000	$ 3,300	$ 2,500	2	50%	$ 2,500
SCR	$ 1,500	$ 2,000	$ 3,300	$ 2,500	2	50%	$ 2,500
DPF	$ 2,500	$ 3,200	$ 5,600	$ 4,100	2	100%	$ 8,200
Fuel system	$ 1,250	$ 1,250	$ 1,500	$ 1,300	2	100%	$ 2,600
Exhaust gas sensors	$ 200	$ 200	$ 200	$ 200	2	100%	$ 400
Turbo	$ 560	$ 570	$ 630	$ 600	2	100%	$ 1,200
EGR System	$ 370	$ 440	$ 660	$ 500	2	50%	$ 500
VVT	$ 1,500	$ 1,500	$ 1,500	$ 1,500	2	50%	$ 1,500
Total for Limit Parts							**$ 19,400**

We have not estimated costs associated with generating limit parts for gasoline engines because we do not expect that over 14,000 pound engines will be used for certification demonstration. Instead, we expect that manufacturers will demonstrate their OBD systems using an engine or vehicle in the under 14,000 pound range and then provide documentation in their certification package showing how their over 14,000 pound engine is represented by the under 14,000 pound demonstration as allowed by the proposed program. While this may also be the case for some diesel engine manufacturers, we have chosen to be conservative in our estimates by assuming that all diesel demonstrations will be over 14,000 pounds.

We have estimated that these costs for limit parts will be incurred every three years going forward. In 2010, one engine family per manufacturer will have to be demonstrated and in 2013 we expect another two engine families per manufacturer to undergo demonstration testing (for diesels). We would then expect engine families to be carried-over for three years at which time another three engines would be demonstrated, etc. This is an over simplification of the carry-over provisions of our certification program, but it serves our purpose here and does not under estimate the costs but rather impacts only when those costs are incurred. We use this same simplifying assumption throughout our analysis of certification and production evaluation testing costs as is shown in Table 11 which shows all our estimated certification and production evaluation testing costs for diesel engines and Table 12 which shows the analogous costs for gasoline engines.

Table 11. OBD Certification and Production Evaluation Testing Costs – Diesel Engines for Over 14,000 Pound Applications

									Production Evaluation Testing Related							
		Demonstration Testing Related				Certification Documentation Related			PE Testing - Scan Tool		PE Testing - Monitors		PE Testing - Ratios			
Year	CY	# of parent test engines	Costs for Limit Parts	DDV Testing Costs	Total DDV Costs	# of parent families	# remaining families	Cert Documentation Costs	# of engine families for testing	PE Costs	# of OBD Groups tested	PE Costs (incl vehicle rental)	# of monitoring groups tested	PE Costs	PE Costs - Total	**Total Certification & PE Testing Costs**
1	2006	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
2	2007	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
3	2008	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
4	2009	10	$ 194,000	$ 728,000	$ 922,000	10	-	$ 50,000	-	$ -	-	$ -	-	$ -	$ -	$ 972,000
5	2010	-	$ -	$ -	$ -	-	-	$ -	10	$ 21,000	10	$ 193,000	30	$ 7,000	$ 221,000	$ 221,000
6	2011	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	30	$ 7,000	$ 7,000	$ 7,000
7	2012	20	$ 388,000	$ 1,456,000	$ 1,844,000	20	45	$ 213,000	-	$ -	-	$ -	30	$ 7,000	$ 7,000	$ 2,064,000
8	2013	-	$ -	$ -	$ -	-	-	$ -	55	$ 115,000	20	$ 255,000	60	$ 14,000	$ 384,000	$ 384,000
9	2014	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 14,000
10	2015	30	$ 582,000	$ 2,184,000	$ 2,766,000	30	35	$ 238,000	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 3,018,000
11	2016	-	$ -	$ -	$ -	-	-	$ -	65	$ 135,000	30	$ 318,000	60	$ 14,000	$ 467,000	$ 467,000
12	2017	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 14,000
13	2018	30	$ 582,000	$ 2,184,000	$ 2,766,000	30	35	$ 238,000	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 3,018,000
14	2019	-	$ -	$ -	$ -	-	-	$ -	65	$ 135,000	30	$ 318,000	60	$ 14,000	$ 467,000	$ 467,000
15	2020	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 14,000
16	2021	30	$ 582,000	$ 2,184,000	$ 2,766,000	30	35	$ 238,000	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 3,018,000
17	2022	-	$ -	$ -	$ -	-	-	$ -	65	$ 135,000	30	$ 318,000	60	$ 14,000	$ 467,000	$ 467,000
18	2023	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 14,000
19	2024	30	$ 582,000	$ 2,184,000	$ 2,766,000	30	35	$ 238,000	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 3,018,000
20	2025	-	$ -	$ -	$ -	-	-	$ -	65	$ 135,000	30	$ 318,000	60	$ 14,000	$ 467,000	$ 467,000
21	2026	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 14,000
22	2027	30	$ 582,000	$ 2,184,000	$ 2,766,000	30	35	$ 238,000	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 3,018,000
23	2028	-	$ -	$ -	$ -	-	-	$ -	65	$ 135,000	30	$ 318,000	60	$ 14,000	$ 467,000	$ 467,000
24	2029	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 14,000
25	2030	30	$ 582,000	$ 2,184,000	$ 2,766,000	30	35	$ 238,000	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 3,018,000
26	2031	-	$ -	$ -	$ -	-	-	$ -	65	$ 135,000	30	$ 318,000	60	$ 14,000	$ 467,000	$ 467,000
27	2032	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 14,000
28	2033	30	$ 582,000	$ 2,184,000	$ 2,766,000	30	35	$ 238,000	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 3,018,000
29	2034	-	$ -	$ -	$ -	-	-	$ -	65	$ 135,000	30	$ 318,000	60	$ 14,000	$ 467,000	$ 467,000
30	2035	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	60	$ 14,000	$ 14,000	$ 14,000
NPV @	3%		$ 2,848,000	$ 10,687,000	$ 13,535,000			$ 1,183,000		$ 640,000		$ 1,620,000		$ 205,000	$ 2,465,000	$ 17,182,000
NPV @	7%		$ 1,611,000	$ 6,046,000	$ 7,657,000			$ 670,000		$ 347,000		$ 910,000		$ 112,000	$ 1,369,000	$ 9,697,000

Table 12. OBD Certification and Production Evaluation Testing Costs – Gasoline Engines for Over 14,000 Pound Applications

									Production Evaluation Testing Related							
		Demonstration Testing Related				Certification Documentation Related			PE Testing - Scan Tool		PE Testing - Monitors		PE Testing - Ratios			
Year	CY	# of parent test engines	Costs for Limit Parts	DDV Testing Costs	Total DDV Costs	# of parent families	# remaining families	Cert Documentation Costs	# of engine families for testing	PE Costs	# of OBD Groups tested	PE Costs (incl vehicle rental)	# of monitoring groups tested	PE Costs	PE Costs - Total	**Total Certification & PE Testing Costs**
1	2006	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
2	2007	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
3	2008	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
4	2009	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
5	2010	-	$ -	$ -	$ -	-	-	$ -	2	$ 4,000	2	$ 39,000	6	$ 1,000	$ 44,000	$ 44,000
6	2011	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 1,000
7	2012	-	$ -	$ -	$ -	-	3	$ 8,000	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 9,000
8	2013	-	$ -	$ -	$ -	-	-	$ -	1	$ 2,000	1	$ 19,000	6	$ 1,000	$ 22,000	$ 22,000
9	2014	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 1,000
10	2015	-	$ -	$ -	$ -	-	3	$ 8,000	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 9,000
11	2016	-	$ -	$ -	$ -	-	-	$ -	3	$ 6,000	3	$ 45,000	6	$ 1,000	$ 52,000	$ 52,000
12	2017	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 1,000
13	2018	-	$ -	$ -	$ -	-	3	$ 8,000	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 9,000
14	2019	-	$ -	$ -	$ -	-	-	$ -	3	$ 6,000	3	$ 45,000	6	$ 1,000	$ 52,000	$ 52,000
15	2020	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 1,000
16	2021	-	$ -	$ -	$ -	-	3	$ 8,000	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 9,000
17	2022	-	$ -	$ -	$ -	-	-	$ -	3	$ 6,000	3	$ 45,000	6	$ 1,000	$ 52,000	$ 52,000
18	2023	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 1,000
19	2024	-	$ -	$ -	$ -	-	3	$ 8,000	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 9,000
20	2025	-	$ -	$ -	$ -	-	-	$ -	3	$ 6,000	3	$ 45,000	6	$ 1,000	$ 52,000	$ 52,000
21	2026	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 1,000
22	2027	-	$ -	$ -	$ -	-	3	$ 8,000	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 9,000
23	2028	-	$ -	$ -	$ -	-	-	$ -	3	$ 6,000	3	$ 45,000	6	$ 1,000	$ 52,000	$ 52,000
24	2029	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 1,000
25	2030	-	$ -	$ -	$ -	-	3	$ 8,000	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 9,000
26	2031	-	$ -	$ -	$ -	-	-	$ -	3	$ 6,000	3	$ 45,000	6	$ 1,000	$ 52,000	$ 52,000
27	2032	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 1,000
28	2033	-	$ -	$ -	$ -	-	3	$ 8,000	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 9,000
29	2034	-	$ -	$ -	$ -	-	-	$ -	3	$ 6,000	3	$ 45,000	6	$ 1,000	$ 52,000	$ 52,000
30	2035	-	$ -	$ -	$ -	-	-	$ -	-	$ -	-	$ -	6	$ 1,000	$ 1,000	$ 1,000
NPV @	3%		$ -	$ -	$ -			$ 39,000		$ 29,000		$ 226,000		$ 16,000	$ 270,000	$ 309,000
NPV @	7%		$ -	$ -	$ -			$ 22,000		$ 16,000		$ 127,000		$ 9,000	$ 152,000	$ 174,000

Focusing first on Table 11, the limit parts costs are first incurred in 2009 in advance of the 2010 model year. The limit parts cost estimate shown in Table 10 ($19,400 per engine) is incurred on one engine family for each of 10 engine manufacturers for a total cost that year of $194,000. This process is carried forward every three years as discussed above. As noted, for gasoline engines, Table 12 shows no limit parts costs or demonstration testing costs.

OBD Certification Demonstration Testing Costs

For costs associated with the actual demonstration testing of OBD parent engines (diesel only), we have estimated that two OBD threshold monitors can be demonstrated during a given day of testing in an emissions test cell. With our estimate of 13 threshold monitors per engine, this means 13 days of testing in an emissions test cell that costs $700 dollars per hour or $5,600 per day to operate. The OBD parent engine, or durability data vehicle (DDV), demonstration testing costs were then calculated by multiplying the test days per engine (13) by the dollars per day ($5,600) and again by the number of demonstration engines being demonstrated for the given model year. The result in 2009 is $728,000 for all 10 engine manufacturers which is incurred one year in advance of implementation because they are certification costs. These costs change depending on the number of engine families undergoing demonstration testing.

OBD Certification Documentation Costs

For certification documentation costs, we have estimated that a certification documentation package for an OBD parent engine would cost $5,000 while it would cost $2,500 for a non-OBD parent engine (i.e., an OBD child rating). We consider this to be a conservative estimate since most child ratings would very likely incur no costs since it would be part of an OBD group represented by the OBD parent engine and should, therefore, require no further certification documentation. Our certification database for the 2004 model year showed 65 diesel engine families and three gasoline engine families in the over 14,000 pound range. Multiplying the expected number of OBD parent engines and child engines being certified for each given year by the estimated costs to generate the certification documentation packages results in the costs shown in Table 11 and Table 12.

OBD Production Evaluation Testing Costs

Also shown are costs for production evaluation (PE) testing. The required production evaluation testing consists of three elements. The first of these is testing to ensure that engines/vehicles comply with the standardization requirements of the OBD rule. This is done by connecting a scan tool to a production vehicle to ensure that the onboard systems communicate properly to an off board device (e.g., a scan tool). We would expect this testing to be done as vehicles roll off the vehicle assembly line. The second element of PE testing is testing to ensure that the OBD monitors are functioning properly. This is done by implanting or simulating malfunctions and determining whether or not the OBD monitors run and detects them. This testing does not involve any actual emissions testing. We would expect this testing to be done on one to three production vehicles but required test beyond one vehicle could be done on production engines rather than production vehicles. The third element of PE testing is testing to ensure that OBD monitors are running and making diagnostic decisions with sufficient frequency in the real world. This is done by scanning the stored OBD information contained in actual in-use vehicles and noting the performance ratios for various non-continuous monitors. Since the production evaluation testing is a post-certification requirement, the costs would be incurred either as new engines/vehicles are rolling off the assembly line or during the six to 12 months following introduction into commerce.

OBD Production Evaluation Testing Costs – Standardization Requirements

To estimate the PE testing costs for verifying the standardization requirements, we have conservatively estimated that the actual test would take four hours and that for each engine family sold the maximum of 10 vehicles would be tested. We have also conservatively estimated that the testing would be done by an engineer at $100,000 per year rather than the more likely choice of a technician at $60,000 per year. Multiplying the number of engine families by the number of vehicles tested per family, the hours per test, and the engineer's cost per hour results in the yearly estimated costs. This cost—shown as "PE testing - scan tool" in the tables—is estimated at $21,000 for diesel engines in 2010 and $4,000 for gasoline engines in 2010. These costs would be incurred on newly introduced OBD-compliant engine families. Therefore, we have estimated costs for testing the engine families from which the OBD parent engine has been chosen. We have also included costs for future model years assuming that most engines undergo enough changes over a three year period to nullify the ability to carry-over from a prior year's certification. When that occurs, we would expect the PE scan tool testing to be done.

OBD Production Evaluation Testing Costs – Monitor Verification

To estimate the PE testing costs for verifying monitors, we have first been conservative by estimating that each manufacturer would conduct the testing for each of three OBD groups. This overestimates these costs because some manufacturers will only have to conduct the testing on one, and others on two, OBD groups because they do not sell enough different engine families to require testing of three. We have also estimated that, as allowed by the proposed rule, the first OBD group tested would have to be tested using a production vehicle while the remaining OBD groups tested would use a production engine. We have estimated the time required to conduct the testing at three weeks and that the testing would be done by an engineer costing $100,000 per year. We have also estimated that it would cost $10,000 to rent or otherwise acquire a vehicle for testing while acquiring an engine would not cost the engine manufacturer anything. Lastly, we have estimated travel costs at $3,000 dollars for testing done on a production vehicle while travel costs for testing on production engines would be zero. The certification and production engine testing cost tables show—in the columns under "PE testing – monitors"—the number of OBD groups undergoing this testing in given years. The 10 shown for 2010 represent one engine tested from each OBD compliant engine family by each of 10 manufacturers. In 2013, we require all engine families to comply but only up to two new engine families must undergo certification demonstration testing and, consequently, PE testing for monitors. For simplicity, as stated elsewhere, we have estimated three new parent engines per manufacturer undergo certification demonstration testing every three years and, consequently, they undergo PE testing for monitors.

OBD Production Evaluation Testing Costs – Performance Ratios

To estimate the PE testing costs for evaluating in-use performance ratios, we have first conservatively estimated that every OBD monitoring group would have to test the maximum of 15 vehicles. An OBD monitoring group is defined first by emissions control architecture (i.e., combination of EGR, turbo, and aftertreatment devices) and secondly by application type (i.e., line haul, urban delivery, other). We have estimated that each manufacturer would have two emissions control architectures and engines sold into each of the three application types. As a result, there would be six monitoring groups per each of 10 different manufacturers for 60 monitoring groups being tested. This is true except for the 2010 to 2012 model years when, since only one engine family is compliant, we have assumed only one emissions control architecture and, therefore, only three OBD monitoring groups for each of 10 manufacturers for 30 total. We have also estimated that the test itself—simply connecting a scan tool and downloading the performance ratio data—would take half an hour to complete by a technician costing $60,000 per year. We have been conservative in our estimate by including costs for this testing in every year even though we would expect that data could be carried over from one year to the next once we are sure that monitors are indeed running at sufficient frequency in-use.

Table 13 shows the cost streams presented above for all fixed costs. The fixed costs consist of R&D, certification, and production evaluation testing costs. Also shown are the 30 year net present values at a three percent discount rate which are $280 million for diesel, $10 million for gasoline and $291 million for the entire industry. The total fixed costs are also shown on a per engine basis using the projected sales shown in Table 2.

Table 13. Total OBD Fixed Costs – Diesel and Gasoline Engines for Over 14,000 Pound Applications

		Diesel					Gasoline					
Year	CY	R&D	Cert/PE Testing	Subtotal	Projected Sales	$/engine	R&D	Cert/PE Testing	Subtotal	Projected Sales	$/engine	Total
1	2006	$ 23,840,000	$ -	$ 23,840,000	639,103	$ 37	$ 1,854,000	$ -	$ 1,854,000	40,976	$ 45	$ 25,694,000
2	2007	$ 23,840,000	$ -	$ 23,840,000	651,393	$ 37	$ 1,854,000	$ -	$ 1,854,000	41,764	$ 44	$ 25,694,000
3	2008	$ 23,840,000	$ -	$ 23,840,000	663,684	$ 36	$ 1,854,000	$ -	$ 1,854,000	42,552	$ 44	$ 25,694,000
4	2009	$ 75,130,000	$ 972,000	$ 76,102,000	675,974	$ 113	$ 2,782,000	$ -	$ 2,782,000	43,340	$ 64	$ 78,884,000
5	2010	$ 51,290,000	$ 221,000	$ 51,511,000	688,265	$ 75	$ 928,000	$ 44,000	$ 972,000	44,128	$ 22	$ 52,483,000
6	2011	$ 51,290,000	$ 7,000	$ 51,297,000	700,555	$ 73	$ 928,000	$ 1,000	$ 929,000	44,916	$ 21	$ 52,226,000
7	2012	$ 51,290,000	$ 2,064,000	$ 53,354,000	712,846	$ 75	$ 928,000	$ 9,000	$ 937,000	45,704	$ 21	$ 54,291,000
8	2013	$ -	$ 384,000	$ 384,000	725,136	$ 1	$ -	$ 22,000	$ 22,000	46,492	$ 0	$ 406,000
9	2014	$ -	$ 14,000	$ 14,000	737,426	$ 0	$ -	$ 1,000	$ 1,000	47,280	$ 0	$ 15,000
10	2015	$ -	$ 3,018,000	$ 3,018,000	749,717	$ 4	$ -	$ 9,000	$ 9,000	48,068	$ 0	$ 3,027,000
11	2016	$ -	$ 467,000	$ 467,000	762,007	$ 1	$ -	$ 52,000	$ 52,000	48,856	$ 1	$ 519,000
12	2017	$ -	$ 14,000	$ 14,000	774,298	$ 0	$ -	$ 1,000	$ 1,000	49,644	$ 0	$ 15,000
13	2018	$ -	$ 3,018,000	$ 3,018,000	786,588	$ 4	$ -	$ 9,000	$ 9,000	50,432	$ 0	$ 3,027,000
14	2019	$ -	$ 467,000	$ 467,000	798,879	$ 1	$ -	$ 52,000	$ 52,000	51,220	$ 1	$ 519,000
15	2020	$ -	$ 14,000	$ 14,000	811,169	$ 0	$ -	$ 1,000	$ 1,000	52,008	$ 0	$ 15,000
16	2021	$ -	$ 3,018,000	$ 3,018,000	823,459	$ 4	$ -	$ 9,000	$ 9,000	52,796	$ 0	$ 3,027,000
17	2022	$ -	$ 467,000	$ 467,000	835,750	$ 1	$ -	$ 52,000	$ 52,000	53,584	$ 1	$ 519,000
18	2023	$ -	$ 14,000	$ 14,000	848,040	$ 0	$ -	$ 1,000	$ 1,000	54,372	$ 0	$ 15,000
19	2024	$ -	$ 3,018,000	$ 3,018,000	860,331	$ 4	$ -	$ 9,000	$ 9,000	55,160	$ 0	$ 3,027,000
20	2025	$ -	$ 467,000	$ 467,000	872,621	$ 1	$ -	$ 52,000	$ 52,000	55,948	$ 1	$ 519,000
21	2026	$ -	$ 14,000	$ 14,000	884,912	$ 0	$ -	$ 1,000	$ 1,000	56,736	$ 0	$ 15,000
22	2027	$ -	$ 3,018,000	$ 3,018,000	897,202	$ 3	$ -	$ 9,000	$ 9,000	57,524	$ 0	$ 3,027,000
23	2028	$ -	$ 467,000	$ 467,000	909,493	$ 1	$ -	$ 52,000	$ 52,000	58,312	$ 1	$ 519,000
24	2029	$ -	$ 14,000	$ 14,000	921,783	$ 0	$ -	$ 1,000	$ 1,000	59,100	$ 0	$ 15,000
25	2030	$ -	$ 3,018,000	$ 3,018,000	934,073	$ 3	$ -	$ 9,000	$ 9,000	59,888	$ 0	$ 3,027,000
26	2031	$ -	$ 467,000	$ 467,000	946,364	$ 0	$ -	$ 52,000	$ 52,000	60,676	$ 1	$ 519,000
27	2032	$ -	$ 14,000	$ 14,000	958,654	$ 0	$ -	$ 1,000	$ 1,000	61,464	$ 0	$ 15,000
28	2033	$ -	$ 3,018,000	$ 3,018,000	970,945	$ 3	$ -	$ 9,000	$ 9,000	62,252	$ 0	$ 3,027,000
29	2034	$ -	$ 467,000	$ 467,000	983,235	$ 0	$ -	$ 52,000	$ 52,000	63,040	$ 1	$ 519,000
30	2035	$ -	$ 14,000	$ 14,000	995,526	$ 0	$ -	$ 1,000	$ 1,000	63,828	$ 0	$ 15,000
NPV @	3%	$ 263,087,000	$ 17,182,000	$ 280,270,000			$ 10,048,000	$ 309,000	$ 10,358,000			$ 290,627,000
NPV @	7%	$ 222,567,000	$ 9,697,000	$ 232,263,000			$ 8,846,000	$ 174,000	$ 9,020,000			$ 241,283,000

3.1.3. Total Costs

Combining the variable cost streams shown in Table 2 and the fixed costs streams shown in Table 13 results in the total estimated costs for the over 14,000 pound proposed OBD requirements. The results are shown in Table 14. As shown, the 30 year net present value at a three percent discount rate is estimated at just under $1 billion with the bulk of those costs being for new hardware in the form of more powerful engine and emissions control system computers. Note that the per engine costs shown in Table 14 use the engine sales estimates shown in Table 2 without accounting for any phase-in (i.e., the costs have been divided by the total new engine sales rather than dividing by the fraction of new engine sales that are compliant).

Table 14. Total Estimated OBD Costs – Diesel and Gasoline Engines for Over 14,000 Pound Applications

		Diesel			Gasoline			
Year	CY	Variable	Fixed	Subtotal	Variable	Fixed	Subtotal	Total
1	2006	$ -	$ 23,840,000	$ 23,840,000	$ -	$ 1,854,000	$ 1,854,000	$ 25,694,000
2	2007	$ -	$ 23,840,000	$ 23,840,000	$ -	$ 1,854,000	$ 1,854,000	$ 25,694,000
3	2008	$ -	$ 23,840,000	$ 23,840,000	$ -	$ 1,854,000	$ 1,854,000	$ 25,694,000
4	2009	$ -	$ 76,102,000	$ 76,102,000	$ -	$ 2,782,000	$ 2,782,000	$ 78,884,000
5	2010	$ 13,531,000	$ 51,511,000	$ 65,042,000	$ 1,060,000	$ 972,000	$ 2,032,000	$ 67,074,000
6	2011	$ 13,772,000	$ 51,297,000	$ 65,069,000	$ 1,079,000	$ 929,000	$ 2,008,000	$ 67,077,000
7	2012	$ 14,014,000	$ 53,354,000	$ 67,368,000	$ 1,098,000	$ 937,000	$ 2,035,000	$ 69,403,000
8	2013	$ 37,588,000	$ 384,000	$ 37,972,000	$ 2,816,000	$ 22,000	$ 2,838,000	$ 40,810,000
9	2014	$ 38,225,000	$ 14,000	$ 38,239,000	$ 2,864,000	$ 1,000	$ 2,865,000	$ 41,104,000
10	2015	$ 38,862,000	$ 3,018,000	$ 41,880,000	$ 2,912,000	$ 9,000	$ 2,921,000	$ 44,801,000
11	2016	$ 39,499,000	$ 467,000	$ 39,966,000	$ 2,959,000	$ 52,000	$ 3,011,000	$ 42,977,000
12	2017	$ 40,136,000	$ 14,000	$ 40,150,000	$ 3,007,000	$ 1,000	$ 3,008,000	$ 43,158,000
13	2018	$ 40,774,000	$ 3,018,000	$ 43,792,000	$ 3,055,000	$ 9,000	$ 3,064,000	$ 46,856,000
14	2019	$ 41,411,000	$ 467,000	$ 41,878,000	$ 3,102,000	$ 52,000	$ 3,154,000	$ 45,032,000
15	2020	$ 42,048,000	$ 14,000	$ 42,062,000	$ 3,150,000	$ 1,000	$ 3,151,000	$ 45,213,000
16	2021	$ 42,685,000	$ 3,018,000	$ 45,703,000	$ 3,198,000	$ 9,000	$ 3,207,000	$ 48,910,000
17	2022	$ 43,322,000	$ 467,000	$ 43,789,000	$ 3,246,000	$ 52,000	$ 3,298,000	$ 47,087,000
18	2023	$ 43,959,000	$ 14,000	$ 43,973,000	$ 3,293,000	$ 1,000	$ 3,294,000	$ 47,267,000
19	2024	$ 44,596,000	$ 3,018,000	$ 47,614,000	$ 3,341,000	$ 9,000	$ 3,350,000	$ 50,964,000
20	2025	$ 45,233,000	$ 467,000	$ 45,700,000	$ 3,389,000	$ 52,000	$ 3,441,000	$ 49,141,000
21	2026	$ 45,870,000	$ 14,000	$ 45,884,000	$ 3,437,000	$ 1,000	$ 3,438,000	$ 49,322,000
22	2027	$ 46,507,000	$ 3,018,000	$ 49,525,000	$ 3,484,000	$ 9,000	$ 3,493,000	$ 53,018,000
23	2028	$ 47,144,000	$ 467,000	$ 47,611,000	$ 3,532,000	$ 52,000	$ 3,584,000	$ 51,195,000
24	2029	$ 47,782,000	$ 14,000	$ 47,796,000	$ 3,580,000	$ 1,000	$ 3,581,000	$ 51,377,000
25	2030	$ 48,419,000	$ 3,018,000	$ 51,437,000	$ 3,628,000	$ 9,000	$ 3,637,000	$ 55,074,000
26	2031	$ 49,056,000	$ 467,000	$ 49,523,000	$ 3,675,000	$ 52,000	$ 3,727,000	$ 53,250,000
27	2032	$ 49,693,000	$ 14,000	$ 49,707,000	$ 3,723,000	$ 1,000	$ 3,724,000	$ 53,431,000
28	2033	$ 50,330,000	$ 3,018,000	$ 53,348,000	$ 3,771,000	$ 9,000	$ 3,780,000	$ 57,128,000
29	2034	$ 50,967,000	$ 467,000	$ 51,434,000	$ 3,818,000	$ 52,000	$ 3,870,000	$ 55,304,000
30	2035	$ 51,604,000	$ 14,000	$ 51,618,000	$ 3,866,000	$ 1,000	$ 3,867,000	$ 55,485,000
NPV @	3%	$ 619,863,000	$ 280,270,000	$ 900,133,000	$ 46,559,000	$ 10,358,000	$ 56,916,000	$ 957,049,000
NPV @	7%	$ 327,800,000	$ 232,263,000	$ 560,063,000	$ 24,653,000	$ 9,020,000	$ 33,673,000	$ 593,736,000

Table 15 shows these costs on a per engine basis by combining the per engine costs shown in Table 2 and Table 13.

Table 15. Total Estimated OBD Costs per Engine for Over 14,000 Pound Applications

		Total $/engine	
Year	CY	Diesel	Gasoline
1	2006	$ 37	$ 45
2	2007	$ 37	$ 44
3	2008	$ 36	$ 44
4	2009	$ 113	$ 64
5	2010	$ 114	$ 70
6	2011	$ 113	$ 69
7	2012	$ 114	$ 69
8	2013	$ 52	$ 61
9	2014	$ 52	$ 61
10	2015	$ 56	$ 61
11	2016	$ 52	$ 62
12	2017	$ 52	$ 61
13	2018	$ 56	$ 61
14	2019	$ 52	$ 62
15	2020	$ 52	$ 61
16	2021	$ 56	$ 61
17	2022	$ 52	$ 62
18	2023	$ 52	$ 61
19	2024	$ 55	$ 61
20	2025	$ 52	$ 62
21	2026	$ 52	$ 61
22	2027	$ 55	$ 61
23	2028	$ 52	$ 61
24	2029	$ 52	$ 61
25	2030	$ 55	$ 61
26	2031	$ 52	$ 61
27	2032	$ 52	$ 61
28	2033	$ 55	$ 61
29	2034	$ 52	$ 61
30	2035	$ 52	$ 61

3.2. Cost Analysis for Under 14,000 Pound Applications

We have used the same approach as described above for estimating costs associated with the under 14,000 pound OBD requirements. Since we have had OBD requirements for many years on such vehicles and engines the costs described here are incremental to past requirements. For hardware costs, we anticipate no new costs since all sensors and actuators should already be present and the computers should already be capable of handling the demands of OBD. We have estimated some new R&D costs to develop the DPF monitor since our current DPF monitoring requirement is to detect only a catastrophic failure while the proposed requirement would be more difficult. This requirement would begin in the 2010 model year and the R&D associated with it would be incurred over the four year period leading up to 2010.

We have estimated that nine manufacturers would be making diesels in the under 14,000 pound market. This estimates that four of the light-duty manufacturers will be selling diesels in the 2010 timeframe. We have also used the same engineering and testing related costs for the under 14,000 pound requirements as used above for the over 14,000 pound requirements. This is being conservative since most testing related costs, especially official emissions testing in a certification test cell, is generally less costly on a chassis dynamometer than on an engine dynamometer. We have also been conservative by developing R&D costs for three manufacturers of engines in the 8,500 to 14,000 pound range despite the fact that they each sell into the over 14,000 pound range and, presumably, their R&D efforts there would suffice for much of their R&D needs in the under 14,000 pound range.

The analogous tables to those presented above are presented here. Table 16 shows the R&D costs for OBD algorithm development and application. We have estimated costs for two new threshold monitors for the new DPF monitoring requirement, for one new threshold monitor for the new NMHC catalyst monitoring requirement, for four and a half (on average) functional monitors associated with DPF and NMHC catalyst monitoring, and for nine continuity monitors associated with DPF and NMHC catalyst monitoring. We have also estimated costs for two engine families per manufacturer with two variants each. The total costs are estimated at $8 million to be spread over the four year period prior to the 2010 implementation date for the new monitoring requirements.

Table 16. R&D Costs for OBD Algorithm Development and Application – Diesel Applications Under 14,000 Pounds

A. Algorithm Development Costs	weeks/monitor	Cost/monitor	# of monitors	Total/Mfr	Total
System Threshold Monitors					
Engineer $	30	$ 63,000			
Technician $	15	$ 19,000			
Subtotal		$ 82,000	3.0	$ 246,000	$ 984,000
System Functional Monitors					
Engineer $	20	$ 42,000			
Technician $	5	$ 6,000			
Subtotal		$ 48,000	4.5	$ 216,000	$ 864,000
CCM Rationality Monitors					
Engineer $	15	$ 31,000			
Technician $	1	$ 1,000			
Subtotal		$ 32,000	4.5	$ 144,000	$ 576,000
CCM Continuity Monitors					
Engineer $	2	$ 4,000			
Technician $	-	$ -			
Subtotal		$ 4,000	9.0	$ 36,000	$ 144,000
Total				$ 642,000	$ 2,568,000

B. Application Costs to each Family	weeks/monitor	Cost/monitor	# of monitors	Total/Family	# families/mfr	Total/Mfr	Total
System Threshold Monitors							
Engineer $	5	$ 10,000					
Technician $	10	$ 13,000					
Subtotal		$ 23,000	3.0	$ 69,000	2	$ 138,000	$ 1,242,000
System Functional Monitors							
Engineer $	5	$ 10,000					
Technician $	10	$ 13,000					
Subtotal		$ 23,000	4.5	$ 104,000	2	$ 208,000	$ 1,872,000
CCM Rationality Monitors							
Engineer $	3	$ 6,000					
Technician $	1	$ 1,000					
Subtotal		$ 7,000	4.5	$ 32,000	2	$ 64,000	$ 576,000
Total				$ 205,000		$ 410,000	$ 3,690,000

C. Application Costs to remaining Variants			Total/Variant	# variants/family	# families/mfr	Total/Mfr	Total
Total			$ 51,000	2.0	2	$ 204,000	$ 1,836,000

The R&D testing costs associated with the R&D effort that we have estimated are shown in Table 17. These costs are estimated at $1.7 million to be spread over the four year period prior to the 2010 implementation date, and just over $800,000 to be spread over the four year period prior to the 2013 implementation date, for the new monitoring requirements.

Table 17. OBD R&D Test Cell Costs – Diesel Applications Under 14,000 Pounds

A. R&D Test Cell Costs - Diesel	Cost for 2007							
Monitor Algorithms	test wks	# of monitors			total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	3	1.0			3.0	$ 19,000	9	$ 171,000
System monitor - functional	2	4.5			9.0	$ 58,000	9	$ 522,000
Rationality monitor	1	4.5			4.5	$ 29,000	9	$ 261,000
Subtotal						$ 106,000		$ 954,000
$ per year for 4 years						$ 26,500		$ 238,500
Monitor Application to each engine family								
factor	30%	# of monitors	# families/mfr		total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.9	1.0	2.0		1.8	$ 12,000	9	$ 108,000
System monitor - functional	0.6	4.5	2.0		5.4	$ 35,000	9	$ 315,000
Rationality monitor	0.3	4.5	2.0		2.7	$ 17,000	9	$ 153,000
Subtotal						$ 64,000		$ 576,000
$ per year for 4 years						$ 16,000		$ 144,000
Monitor Application to each engine family variant								
factor	10%	# of monitors	# families/mfr	additional variants	total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.3	1.0	2.0	1.0	0.6	$ 4,000	9	$ 36,000
System monitor - functional	0.2	4.5	2.0	1.0	1.8	$ 12,000	9	$ 108,000
Rationality monitor	0.1	4.5	2.0	1.0	0.9	$ 6,000	9	$ 54,000
Subtotal						$ 22,000		$ 198,000
$ per year for 4 years						$ 5,500		$ 49,500
Total R&D Test Cell Costs						$ 192,000		$ 1,728,000
$ per year for 4 years						$ 48,000		$ 432,000

B. R&D Test Cell Costs - Diesel	Costs for 2010							
Monitor Algorithms	test wks	# of monitors			total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	3.0	2.0			6.0	$ 38,000	9	$ 342,000
System monitor - functional	2.0	-			-	$ -	9	$ -
Rationality monitor	1.0	-			-	$ -	9	$ -
Subtotal						$ 38,000		$ 342,000
$ per year for 4 years						$ 9,500		$ 85,500
Monitor Application to each engine family								
factor	30%	# of monitors	# families/mfr		total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.9	2.0	2.0		3.6	$ 23,000	9	$ 207,000
System monitor - functional	0.6	-	2.0		-	$ -	9	$ -
Rationality monitor	0.3	-	2.0		-	$ -	9	$ -
Subtotal						$ 23,000		$ 207,000
$ per year for 4 years						$ 5,750		$ 51,750
Monitor Application to each engine family variant								
factor	10%	# of monitors	# families/mfr	additional variants	total test wks	Costs/mfr	# mfrs	Total
System monitor - threshold	0.3	2.0	2.0	4.0	4.8	$ 31,000	9	$ 279,000
System monitor - functional	0.2	-	2.0	4.0	-	$ -	9	$ -
Rationality monitor	0.1	-	2.0	4.0	-	$ -	9	$ -
Subtotal						$ 31,000		$ 279,000
$ per year for 4 years								
Total R&D Test Cell Costs						$ 92,000		$ 828,000
$ per year for 4 years						$ 23,000		$ 207,000

For certification costs, we have first estimated costs for limit parts for certification demonstration. These costs are shown in Table 18 as $4,600 per vehicle. The projected sales numbers shown in the table are based loosely on the 2004 certification database and engineering judgement.

Table 18. Cost for OBD Certification Demonstration Limit Parts – Under 14,000 Pound Diesel Applications

Diesel Engines	LDD	8.5-14K	Sales Weighted	Parts needed (incl errors)	Percent needing part	Fleet Weighted
Displacement	2.5	6				
2010 Projected Sales less CA sales	100,000	470,000	570,000			
NOx Adsorber	$ -	$ -	$ -	2	50%	$ -
SCR	$ -	$ -	$ -	2	50%	$ -
DPF	$ 1,250	$ 2,500	$ 2,281	2	100%	$ 4,600
Total for Limit Parts						$ 4,600

Table 19 shows the estimated costs for demonstration testing. Note that we have not estimated costs for certification documentation since all of the under 14,000 pound diesel applications are already generating and submitting OBD certification documentation. We have also estimated no costs for production evaluation testing since we do not have requirements for such testing in our under 14,000 pound OBD program. We have estimated costs for a total of 18 engine families with only one per manufacturer being demonstrated every three years, on average. The 30 year net present value costs for certification demonstration testing are estimated at $3 million and $2 million at a three percent and a seven percent discount rate, respectively.

The total costs for under 14,000 pound diesel applications are shown in Table 20. The per vehicle numbers assume a two percent sales growth rate using the projected sales number shown in Table 18, and entries of $0 represent costs less than $1 per vehicle. The 30 year net present value of total costs are estimated at $13 million and $11 million at a three percent and a seven percent discount rate, respectively. Importantly, these costs represent the incremental costs of the proposed additional OBD requirements, as compared to our current OBD requirements, for under 14,000 pound applications and do not represent the total costs for under 14,000 pound OBD.

Table 19. OBD Certification and Production Evaluation Testing Costs – Diesel Applications Under 14,000 Pounds

						Production Evaluation Testing Related							
		Demonstration Testing Related				PE Testing - Scan Tool		PE Testing - Monitors		PE Testing - Ratios			
Year	CY	# of parent test engines	Costs for Limit Parts	DDV Testing Costs	Total DDV Costs	# of engine families for testing	PE Costs	# of OBD Groups tested	PE Costs (incl vehicle rental)	# of monitoring groups tested	PE Costs	PE Costs - Total	**Total Certification & PE Testing Costs**
1	2006	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
2	2007	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
3	2008	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
4	2009	9	$ 41,000	$ 655,000	$ 696,000	-	$ -	-	$ -	-	$ -	$ -	$ 696,000
5	2010	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
6	2011	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
7	2012	6	$ 28,000	$ 437,000	$ 465,000	-	$ -	-	$ -	-	$ -	$ -	$ 465,000
8	2013	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
9	2014	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
10	2015	6	$ 28,000	$ 437,000	$ 465,000	-	$ -	-	$ -	-	$ -	$ -	$ 465,000
11	2016	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
12	2017	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
13	2018	6	$ 28,000	$ 437,000	$ 465,000	-	$ -	-	$ -	-	$ -	$ -	$ 465,000
14	2019	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
15	2020	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
16	2021	6	$ 28,000	$ 437,000	$ 465,000	-	$ -	-	$ -	-	$ -	$ -	$ 465,000
17	2022	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
18	2023	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
19	2024	6	$ 28,000	$ 437,000	$ 465,000	-	$ -	-	$ -	-	$ -	$ -	$ 465,000
20	2025	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
21	2026	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
22	2027	6	$ 28,000	$ 437,000	$ 465,000	-	$ -	-	$ -	-	$ -	$ -	$ 465,000
23	2028	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
24	2029	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
25	2030	6	$ 28,000	$ 437,000	$ 465,000	-	$ -	-	$ -	-	$ -	$ -	$ 465,000
26	2031	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
27	2032	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
28	2033	6	$ 28,000	$ 437,000	$ 465,000	-	$ -	-	$ -	-	$ -	$ -	$ 465,000
29	2034	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
30	2035	-	$ -	$ -	$ -	-	$ -	-	$ -	-	$ -	$ -	$ -
NPV @	3%		$ 173,000	$ 2,709,000	$ 2,882,000		$ -		$ -		$ -	$ -	$ 2,882,000
NPV @	7%		$ 107,000	$ 1,689,000	$ 1,797,000		$ -		$ -		$ -	$ -	$ 1,797,000

Table 20. Total Estimated OBD Costs – Diesel Applications Under 14,000 Pounds

Year	CY	R&D	Cert/PE Testing	Hardware	Total	Projected Sales	$/vehicle
1	2006	$ 2,455,500	$ -	$ -	$ 2,455,500	570,000	$ 4
2	2007	$ 2,455,500	$ -	$ -	$ 2,455,500	581,400	$ 4
3	2008	$ 2,455,500	$ -	$ -	$ 2,455,500	592,800	$ 4
4	2009	$ 2,662,500	$ 696,000	$ -	$ 3,358,500	604,200	$ 6
5	2010	$ 207,000	$ -	$ -	$ 207,000	615,600	$ 0
6	2011	$ 207,000	$ -	$ -	$ 207,000	627,000	$ 0
7	2012	$ 207,000	$ 465,000	$ -	$ 672,000	638,400	$ 1
8	2013	$ -	$ -	$ -	$ -	649,800	$ -
9	2014	$ -	$ -	$ -	$ -	661,200	$ -
10	2015	$ -	$ 465,000	$ -	$ 465,000	672,600	$ 1
11	2016	$ -	$ -	$ -	$ -	684,000	$ -
12	2017	$ -	$ -	$ -	$ -	695,400	$ -
13	2018	$ -	$ 465,000	$ -	$ 465,000	706,800	$ 1
14	2019	$ -	$ -	$ -	$ -	718,200	$ -
15	2020	$ -	$ -	$ -	$ -	729,600	$ -
16	2021	$ -	$ 465,000	$ -	$ 465,000	741,000	$ 1
17	2022	$ -	$ -	$ -	$ -	752,400	$ -
18	2023	$ -	$ -	$ -	$ -	763,800	$ -
19	2024	$ -	$ 465,000	$ -	$ 465,000	775,200	$ 1
20	2025	$ -	$ -	$ -	$ -	786,600	$ -
21	2026	$ -	$ -	$ -	$ -	798,000	$ -
22	2027	$ -	$ 465,000	$ -	$ 465,000	809,400	$ 1
23	2028	$ -	$ -	$ -	$ -	820,800	$ -
24	2029	$ -	$ -	$ -	$ -	832,200	$ -
25	2030	$ -	$ 465,000	$ -	$ 465,000	843,600	$ 1
26	2031	$ -	$ -	$ -	$ -	855,000	$ -
27	2032	$ -	$ -	$ -	$ -	866,400	$ -
28	2033	$ -	$ 465,000	$ -	$ 465,000	877,800	$ 1
29	2034	$ -	$ -	$ -	$ -	889,200	$ -
30	2035	$ -	$ -	$ -	$ -	900,600	$ -
NPV @	3%	$ 9,831,000	$ 2,882,000	$ -	$ 12,714,000		
NPV @	7%	$ 8,890,000	$ 1,797,000	$ -	$ 10,686,000		

3.3. Updated 2007/2010 HD Highway Costs Including OBD

Table 21 shows the cost estimates for the 2007/2010 heavy-duty highway program. As shown, the 30 year net present value cost at a three percent discount rate was estimated at $70 billion with $25 billion of that being engine related costs.

Table 21. Costs of the 2007/2010 Heavy-duty Highway Program*

(All Costs in $Millions; 1999 Dollars)

Year	Calendar Year	Diesel Engines HD2007 FRM	Gasoline Vehicles & Engines HD2007 FRM	Diesel Fuel	Total Costs - Engines, Fuel
1	2006	$ (80)	$ -	$ 880	$ 799
2	2007	$ 1,266	$ -	$ 1,786	$ 3,052
3	2008	$ 1,321	$ 46	$ 1,809	$ 3,177
4	2009	$ 1,072	$ 80	$ 1,904	$ 3,056
5	2010	$ 1,520	$ 81	$ 2,014	$ 3,615
6	2011	$ 1,225	$ 82	$ 2,128	$ 3,434
7	2012	$ 1,133	$ 83	$ 2,160	$ 3,376
8	2013	$ 1,157	$ 78	$ 2,192	$ 3,427
9	2014	$ 1,180	$ 79	$ 2,225	$ 3,484
10	2015	$ 1,141	$ 80	$ 2,258	$ 3,480
11	2016	$ 1,156	$ 82	$ 2,292	$ 3,530
12	2017	$ 1,159	$ 83	$ 2,327	$ 3,568
13	2018	$ 1,182	$ 84	$ 2,362	$ 3,628
14	2019	$ 1,205	$ 85	$ 2,397	$ 3,687
15	2020	$ 1,226	$ 86	$ 2,433	$ 3,746
16	2021	$ 1,247	$ 87	$ 2,469	$ 3,804
17	2022	$ 1,268	$ 89	$ 2,506	$ 3,863
18	2023	$ 1,288	$ 90	$ 2,544	$ 3,921
19	2024	$ 1,307	$ 91	$ 2,582	$ 3,980
20	2025	$ 1,326	$ 92	$ 2,621	$ 4,039
21	2026	$ 1,344	$ 93	$ 2,660	$ 4,098
22	2027	$ 1,362	$ 94	$ 2,700	$ 4,157
23	2028	$ 1,380	$ 95	$ 2,741	$ 4,217
24	2029	$ 1,398	$ 97	$ 2,782	$ 4,276
25	2030	$ 1,415	$ 98	$ 2,824	$ 4,337
26	2031	$ 1,432	$ 99	$ 2,866	$ 4,397
27	2032	$ 1,450	$ 100	$ 2,909	$ 4,459
28	2033	$ 1,467	$ 101	$ 2,953	$ 4,521
29	2034	$ 1,484	$ 102	$ 2,997	$ 4,583
30	2035	$ 1,500	$ 104	$ 3,042	$ 4,646
NPV @	3%	$ 23,721	$ 1,514	$ 45,191	$ 70,427
NPV @	7%	$ 14,369	$ 877	$ 26,957	$ 42,203

* EPA420-R-00-026; Table V.D-1 & Appendix VI-B; December 2000.

As shown in Table 14 (OBD costs for over 14,000 pounds) and Table 20 (OBD costs for under 14,000 pounds), the 2007/2010 program costs far outweigh the OBD related costs of $1 billion and $13 million, respectively. The updated 2007/2010 program costs are shown in Table 22. Note that the 2007/2010 program costs were generated using 1999 dollars. Normally, we would adjust 1999 dollars to 2004 dollars to make all costs consistent. However, we consulted the Producer Price Index (PPI) for "Motor vehicle parts manufacturing-new exhaust system parts" developed by the Bureau of Labor Statistics and found that the annual PPI adjustment for such parts had actually decreased from 1999 to 2004.[20] The PPI data are shown in Table 23. This suggests that the cost to produce exhaust system parts has decreased since 1999 (note that the preliminary data for 2005 suggest that the PPI adjustment for 2005 will be roughly equal to that for 1999). For clarity, rather than adjusting downward the 2007/2010 program costs from 1999 dollars, or adjusting upward the OBD costs from 2004 dollars, we have chosen to present the 2007/2010 costs as they were presented in that final rule alongside the OBD costs as presented in sections 2 and 3 of this report. In short, the costs shown in Table 22 ignore the PPI effect because it is, essentially, negligible over the timeframe of consideration.

Table 22. Updated 2007/2010 Program Costs Including New OBD-Related Costs

(All costs in $Millions)

Year	Calendar Year	Diesel Engines HD2007 FRM	Diesel Engines >14K OBD	Diesel Applications <14K OBD*	Gasoline Vehicles & Engines HD2007 FRM	Gasoline Engines >14K OBD	Diesel Fuel	Total Costs - Engines, OBD, Fuel
1	2006	$ (80)	$ 23.8	$ 2.5	$ -	$ 1.9	$ 880	$ 828
2	2007	$ 1,266	$ 23.8	$ 2.5	$ -	$ 1.9	$ 1,786	$ 3,080
3	2008	$ 1,321	$ 23.8	$ 2.5	$ 46	$ 1.9	$ 1,809	$ 3,204
4	2009	$ 1,072	$ 76.1	$ 3.4	$ 80	$ 2.8	$ 1,904	$ 3,138
5	2010	$ 1,520	$ 65.0	$ 0.2	$ 81	$ 2.0	$ 2,014	$ 3,682
6	2011	$ 1,225	$ 65.1	$ 0.2	$ 82	$ 2.0	$ 2,128	$ 3,502
7	2012	$ 1,133	$ 67.4	$ 0.7	$ 83	$ 2.0	$ 2,160	$ 3,446
8	2013	$ 1,157	$ 38.0	$ -	$ 78	$ 2.8	$ 2,192	$ 3,468
9	2014	$ 1,180	$ 38.2	$ -	$ 79	$ 2.9	$ 2,225	$ 3,525
10	2015	$ 1,141	$ 41.9	$ 0.5	$ 80	$ 2.9	$ 2,258	$ 3,524
11	2016	$ 1,156	$ 40.0	$ -	$ 82	$ 3.0	$ 2,292	$ 3,573
12	2017	$ 1,159	$ 40.2	$ -	$ 83	$ 3.0	$ 2,327	$ 3,612
13	2018	$ 1,182	$ 43.8	$ 0.5	$ 84	$ 3.1	$ 2,362	$ 3,675
14	2019	$ 1,205	$ 41.9	$ -	$ 85	$ 3.2	$ 2,397	$ 3,732
15	2020	$ 1,226	$ 42.1	$ -	$ 86	$ 3.2	$ 2,433	$ 3,790
16	2021	$ 1,247	$ 45.7	$ 0.5	$ 87	$ 3.2	$ 2,469	$ 3,852
17	2022	$ 1,268	$ 43.8	$ -	$ 89	$ 3.3	$ 2,506	$ 3,910
18	2023	$ 1,288	$ 44.0	$ -	$ 90	$ 3.3	$ 2,544	$ 3,969
19	2024	$ 1,307	$ 47.6	$ 0.5	$ 91	$ 3.4	$ 2,582	$ 4,031
20	2025	$ 1,326	$ 45.7	$ -	$ 92	$ 3.4	$ 2,621	$ 4,088
21	2026	$ 1,344	$ 45.9	$ -	$ 93	$ 3.4	$ 2,660	$ 4,146
22	2027	$ 1,362	$ 49.5	$ 0.5	$ 94	$ 3.5	$ 2,700	$ 4,209
23	2028	$ 1,380	$ 47.6	$ -	$ 95	$ 3.6	$ 2,741	$ 4,267
24	2029	$ 1,398	$ 47.8	$ -	$ 97	$ 3.6	$ 2,782	$ 4,328
25	2030	$ 1,415	$ 51.4	$ 0.5	$ 98	$ 3.6	$ 2,824	$ 4,393
26	2031	$ 1,432	$ 49.5	$ -	$ 99	$ 3.7	$ 2,866	$ 4,450
27	2032	$ 1,450	$ 49.7	$ -	$ 100	$ 3.7	$ 2,909	$ 4,512
28	2033	$ 1,467	$ 53.3	$ 0.5	$ 101	$ 3.8	$ 2,953	$ 4,579
29	2034	$ 1,484	$ 51.4	$ -	$ 102	$ 3.9	$ 2,997	$ 4,638
30	2035	$ 1,500	$ 51.6	$ -	$ 104	$ 3.9	$ 3,042	$ 4,701
NPV @	3%	$ 23,721	$ 900	$ 13	$ 1,514	$ 57	$ 45,191	$ 71,395
NPV @	7%	$ 14,369	$ 560	$ 11	$ 877	$ 34	$ 26,957	$ 42,807

* Note that the 2007/2010 final rule did not apply to <8,500 pound applications.

Table 23. Producer Price Index Data for Motor Vehicle Exhaust System Parts*

Series Id: PCU3363993363993
Industry: All other motor vehicle parts mfg
Product: Exhaust system parts, new
Base Date: 8812

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1995	111.9	111.8	113.5	113.5	113.7	113.7	113.7	113.7	113.5	113.5	116	116	113.7
1996	116	116.5	116.5	116.5	116.4	117.1	117.1	117.1	117.1	117.1	117.5	117.5	116.9
1997	117.5	119.1	119.1	118.6	118.6	118.6	118.4	118.4	118.3	118.2	118.1	118.1	118.4
1998	119.8	119.7	119.7	119.7	119.7	119.2	119	119	119	119	119	118.7	119.3
1999	119	119	119	119	119	118.9	118.9	118.9	118.8	118.8	118.8	118.6	118.9
2000	118.6	118.6	118.6	118.4	118.1	118.2	118.2	118.3	118.3	117.1	117.1	117.2	118.1
2001	117.2	123.6	123.5	122.7	122.7	122.7	121	120.1	120.1	119.9	119.9	119.9	121.1
2002	119.9	119.6	119.6	116.5	116.1	116.1	116.1	115.7	115.7	115.9	116.1	116.1	116.9
2003	116.1	116.1	116.1	115.9	115.9	115.9	115.9	115.9	115.9	115.9	115.9	115.9	116
2004	115.9	116.2	116.2	116.1	116.1	116.4	116.4	116.4	116.4	116.4	116.4	116.4	116.3
2005	116.4	116.4	116.4	116.4	118.2	118.2	116.4(P)	116.4(P)	118.2(P)	118.2(P)			

P : Preliminary. All indexes are subject to revision four months after original publication.

* See www.bls.gov/ppi.

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[17] 66 FR 5002 and 69 FR 38958, respectively.

[18] Board approved as of July 21, 2005 (see 13 CCR 1971.1).

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[19] "Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines," EPA420-R-04-007, May 2004.

[20] See www.bls.gov/ppi; All other motor vehicle parts mfg; Exhaust system parts, new; series ID PCU3363993363993; Base date 8812.