MEMORANDUM

DATE: May 31, 2005

SUBJECT: Control Costs for NOx Adsorbers and CDPF for CI Engines

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The purpose of this memorandum is to present information on the cost of controls for stationary compression ignition (CI) internal combustion engines (ICE). The cost information presented in this memorandum will be used to estimate cost impacts associated with the new source performance standards (NSPS) for stationary CI ICE. The control technologies discussed in this memorandum are NOx adsorbers and catalyzed diesel particulate filters (CDPF), which are the technologies that are the basis for the proposed emissions standards for the control of NOx and PM, respectively.

Introduction

The costs of NOx adsorbers and CDPF presented in this memorandum were estimated based on information obtained from the final regulatory impact analysis (RIA) for nonroad diesel engines developed by the Office of Transportation and Air Quality (OTAQ) published in May 2004.[1] The following sections describe how the capital and annual costs for these control technologies were derived based on information from the RIA.

Control Costs

NOx Adsorbers

Table 6.2-11 of the RIA presented NOx adsorber system costs in 2002 dollars for

[1]Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines. Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency. May 2004. EPA/420-R-04-007.

engines of varying size and displacement. Several costs were presented in Table 6.2-11 including the baseline cost to buyer (near term and long term), the cost to buyer with highway learning (near term and long term), and the cost to buyer with nonroad learning (long term).

The RIA indicated that costs for NOx adsorbers were estimated based on the methodology used in the 2007 heavy-duty highway engines rulemaking. This rulemaking sets final emissions standards for 2007 and later engines used in heavy-duty highway vehicles. It was also indicated that the control technologies expected to be used to show compliance with the nonroad standards are the same as those expected for highway engines. The long term costs presented by OTAQ assume that control system costs will decrease over time as manufacturers become more experienced with production and can make changes, adjustments, and improvements lowering the cost of production. According to OTAQ, this is often described as the manufacturing learning curve. In the RIA, it was indicated that there would be a learning curve associated with the heavy-duty highway engine rule as well as the nonroad rule for diesel engines. Nonroad diesel engines currently do not employ any type of NOx aftertreatment and CDPF have only been applied in limited applications, according to OTAQ. These are therefore new technologies for nonroad diesel engines and will involve a learning curve beyond the learning in response to the heavy-duty highway rule. The standards for nonroad CI engines follow the implementation of the heavy-duty highway engines rule and OTAQ indicated that the 2007 heavy-duty highway engines rule was used as the baseline level of learning for nonroad engines.

Stationary CI engines are similar to nonroad CI engines and EPA believes the costs associated with a NOx adsorber developed for nonroad CI engines would be similar to NOx adsorber costs for stationary CI engines. Also, the NSPS will require stationary CI engines to meet the nonroad CI engine emissions standards. The EPA therefore feels it is appropriate to use the nonroad control costs developed by OTAQ for stationary CI engines. The EPA believes that it is appropriate to take into account the learning curve when estimating the cost of NOx adsorbers. The technology is currently considered a new technology and EPA expects that as the technology is more widely applied, system costs will decrease in the future. The control costs would be higher if the near term costs presented by OTAQ were used. Since the long term costs include a learning curve effect for portions of the NOx adsorber system, EPA feels it is justified in using these costs. Finally, since the technology is not available yet but is expected to be available in approximately 2011, EPA believes that for NOx adsorbers it is appropriate to follow the timeline for the nonroad rulemaking (2011) and therefore use the costs estimated for the nonroad CI engine rule.

In order to develop a relationship between the NOx adsorber system cost and engine size to determine the capital and annual costs for different engine sizes, EPA generated a plot of the NOx adsorber system costs obtained from Table 6.2-11 of the RIA versus the engine horsepower (HP). Assuming a linear trend, the following functions were developed:

Baseline Cost to Buyer	\$4.0(x) + \$213	R^2=0.9926
Cost to Buyer w/Highway Learning	\$3.3(x) + \$194	R^2=0.9926
Cost to Buyer w/Nonroad Learning	\$2.8(x) + \$178	R^2=0.9927

where x represents the engine size in HP. The linear regression plot is included in Attachment A.

Based on the above functions developed by EPA, the purchased equipment cost was calculated for different engine sizes. The capital and annual costs were determined using the Office of Air Quality Planning and Standards (OAQPS) Control Cost Methodology described below:

Determine:
1 - Total Capital Costs
2 - Total Annual Costs

1 - Total Capital Cost Components and Factors:

Total Capital Cost (TCC) = Direct Costs (DC) + Indirect Costs (IC)

1.1 - Direct Costs (DC): DC = PEC + DIC

1.1.1 - Purchased Equipment Costs (PEC):

- Control Device and Auxiliary Equipment (EC)
- Instrumentation (10% of EC)
- Sales Tax (3% of EC)
- Freight (5% of EC)

PEC = 118% EC

1.1.2 - Direct Installation Costs (DIC)

- Foundations and Supports (8% of PEC)
- Handling and Erection (14% of PEC)
- Electrical (4% of PEC)
- Piping (2% of PEC)
- Insulation for Ductwork (1% of PEC)
- Painting (1% of PEC)

DIC = 30% PEC

DC = PEC + 0.3 PEC = 1.3 PEC

1.2 - Indirect Costs (IC): IC = ICC + C

1.2.1 - Indirect Installation Costs (IIC)

- Engineering (10% of PEC)
- Construction and Field Expenses (5% of PEC)
- Contractor Fees (10% of PEC)
- Startup (2% of PEC)
- Performance Test (1% of PEC)

IIC = 28% PEC = 0.28 PEC

1.2.2 - Contingencies (C) (3% of PEC)

- Equipment Redesign and Modifications
- Cost Escalations
- Delays in Startup

C = 3% PEC = 0.03 PEC

IC = 0.28 PEC + 0.03 PEC = 0.31 PEC

TCC = 1.3 PEC + 0.31 PEC = 1.61 PEC = 1.61 (1.18 EC) = 1.9 EC

2 - Total Annual Cost Elements and Factors

Total Annual Cost (TAC) = Direct Annual Costs (DC) + Indirect Annual Costs (IC)

2.1 - Direct Annual Costs (DC):

- Utilities
- Operating Labor
- Maintenance
- Annual Compliance Test
- Catalyst Cleaning
- Catalyst Replacement
- Catalyst Disposal

2.2 - Indirect Annual Costs (IC)

- Overhead (60% of operating labor and maintenance costs)
- Fuel Penalty
- Property Tax (1% of TCC)
- Insurance (1% of TCC)
- Administrative Charges (2% of TCC)
- Capital Recovery = $\{I(1+I)^n/((1+I)^n-1)*TCC\}$ where I is the interest rate, and n is the equipment life.

The information from OTAQ's RIA did not include any direct annual costs for NOx adsorbers such as operating and maintenance costs. These costs were therefore assumed to be zero. Indirect annual costs were calculated based on the OAQPS Control Cost Methodology assuming an equipment life of 20 years and an interest rate of 7 percent. According to OTAQ, the fuel penalty associated with NOx adsorbers is estimated to be about 1 percent. For the purposes of estimating indirect annual costs, EPA assumed the fuel penalty was negligible. The estimated capital and annual costs associated with a NOx adsorber applied to engines of varying sizes are shown in Table 1.

Table 1: Capital and Annual Costs Associated with a NOx Adsorber

Engine Size (HP)	Purchased Equipment Cost	Total Capital Cost	Total Annual Cost	Total Capital Cost ($/HP)	Total Annual Cost ($/HP)
75	$388	$737	$99	$10	$1
135	$556	$1,056	$142	$8	$1
238	$844	$1,604	$216	$7	$1
400	$1,298	$2,466	$331	$6	$1
750	$2,278	$4,328	$582	$6	$1
3000	$8,578	$16,298	$2,190	$5	$1
			Average	**$7**	**$1**

*Costs include the costs of an oxidation catalyst and are based on the cost to buyer with nonroad learning.

<u>CDPF</u>

Table 6.2-13 of the RIA presented CDPF system costs in 2002 dollars for engines of varying size and displacement. Several costs were presented in Table 6.2-13 including the baseline cost to buyer (near term and long term), the cost to buyer with highway learning (near term and long term), and the cost to buyer with nonroad learning (long

term). The EPA will require emissions standards for stationary CI engines that are based on the use of CDPF following the schedule for nonroad CI engines. The EPA therefore believes that for CDPF it is appropriate to follow the nonroad rulemaking and use the cost for CDPF that incorporates the nonroad engine learning curve. As with the NOx adsorber system costs, EPA believes that it is also appropriate to use the long term costs associated with CDPF. This technology is also relatively new and EPA expects the costs of CDPF to decrease over time as the technology is more frequently applied to CI engines. The control costs would be higher if near term costs from OTAQ or current costs provided by engine control vendors for CDPF were used.

In order to develop a relationship between the CDPF system cost and engine size, EPA again developed a linear regression of the CDPF system costs obtained from Table 6.2-13 of the RIA versus the engine HP. Based on the regression analysis, the following functions were developed:

Baseline Cost to Buyer	\$5.8(x) + \$117	R^2=0.9936
Cost to Buyer w/Highway Learning	\$4.7(x) + \$93	R^2=0.9936
Cost to Buyer w/Nonroad Learning	\$3.7(x) + \$75	R^2=0.9936

where x represents the engine size in HP. The linear regression plot is included in Attachment A.

Information in the RIA also included costs for a CDPF regeneration system. According to OTAQ, some form of active regeneration is expected to be used as a backup to the passive regeneration ability of the CDPF. It was further stated in the RIA that there are challenges associated with implementing CDPF with nonroad applications beyond those of highway applications. It is anticipated that some additional hardware beyond the filter itself may be required in order to ensure that regeneration of the filter occurs. This may include new fuel control strategies that force regeneration or it may include an exhaust system fuel injector to inject fuel upstream of the CDPF to provide the necessary regeneration. The estimated costs of such a system were presented in Table 6.2-16 of the RIA for engines of varying size and displacement. Based on the information in Table 6.2-16, EPA developed the following linear relationship between the CDPF regeneration system cost and engine size:

Cost to Buyer w/Learning - Regeneration	\$0.18(x) + \$123	R^2=0.9706

where x represents the engine size in HP. The linear regression plot is included in Attachment A.

Note that the cost function shown above for the regeneration system applies to engines with a direct injection (DI) fuel system. In a DI fuel system, fuel is injected directly into the main combustion chamber. In an indirect injection (IDI) fuel system, fuel is injected into a small pre chamber above the main combustion chamber where combustion begins. The main combustion chamber is lit off by the flame from the small chamber. According to Caterpillar, a major manufacturer of stationary diesel engines, all Caterpillar engines manufactured in the last 15 years have been DI engines. An IDI fuel system is less favorable because it is less fuel efficient according to the manufacturer, but there are still a few manufacturers using the IDI design, but there are fewer each year. The EPA therefore expects that most stationary diesel engines would have a DI fuel system and has included in the cost of CDPF the cost of a regeneration system for engines with a DI fuel system. The regeneration system costs for engines with IDI fuel systems would be twice as much as the regeneration system costs for engines with DI fuel systems. Based on the functions developed by EPA, the purchased equipment cost was calculated for different engine sizes using DI fuel systems. The capital and annual costs were determined using the OAQPS Control Cost Methodology as previously described. Maintenance costs associated with a CDPF system were obtained from Table 6.2-30 of the RIA. The table indicated that a maintenance interval of 3,000 hours for engines below 175 HP and 4,500 hours for engines above 175 HP was appropriate. Table 6.2-30 further indicated that the estimated costs associated with maintenance was $65 for engines up to 600 HP and $260 per event for engines above 600 HP. The EPA used these costs to estimate the annual maintenance costs associated with CDPF for prime and emergency engines as the hours of operation affect the frequency of maintenance. It was assumed that prime engines operate 1,000 hours per year and emergency engines operate 37 hours per year. An equipment life of 20 years and an interest rate of 7 percent was used to estimate the indirect annual costs. According to OTAQ, the fuel penalty associated with CDPF is estimated to be about 1 percent. For the purposes of estimating indirect annual costs, EPA assumed the fuel penalty was negligible. This is consistent with information received from a CDPF vendor who indicated that the fuel penalty associated with CDPF would be negligible. The capital and annual costs associated with a CDPF system are shown in Table 2.

Table 2: Capital and Annual Costs Associated with a CDPF

Engine Size (HP)	Purchased Equipment Cost	Total Capital Cost	Total Annual Cost		Total Capital Cost ($/HP)	Total Annual Cost ($/HP)	
			Prime	Emergency		Prime	Emergency
75	$489	$929	$160	$126	$12	$2	$2
135	$722	$1,371	$219	$186	$10	$2	$1
238	$1,121	$2,131	$309	$287	$9	$1	$1
400	$1,750	$3,325	$470	$448	$8	$1	$1

Engine Size (HP)	Purchased Equipment Cost	Total Capital Cost	Total Annual Cost		Total Capital Cost ($/HP)	Total Annual Cost ($/HP)	
			Prime	Emergency		Prime	Emergency
750	$3,108	$5,905	$840	$795	$8	$1	$1
3000	$11,838	$22,492	$3,115	$3,026	$7	$1	$1
				Average	**$9**	**$1**	**$1**

*Costs include the costs of an oxidation catalyst and are based on the cost to buyer with nonroad learning.
**Costs presented are for engines with a DI fuel system. Costs for engines with an IDI fuel system would be twice the costs of engines with a DI fuel system.

Summary

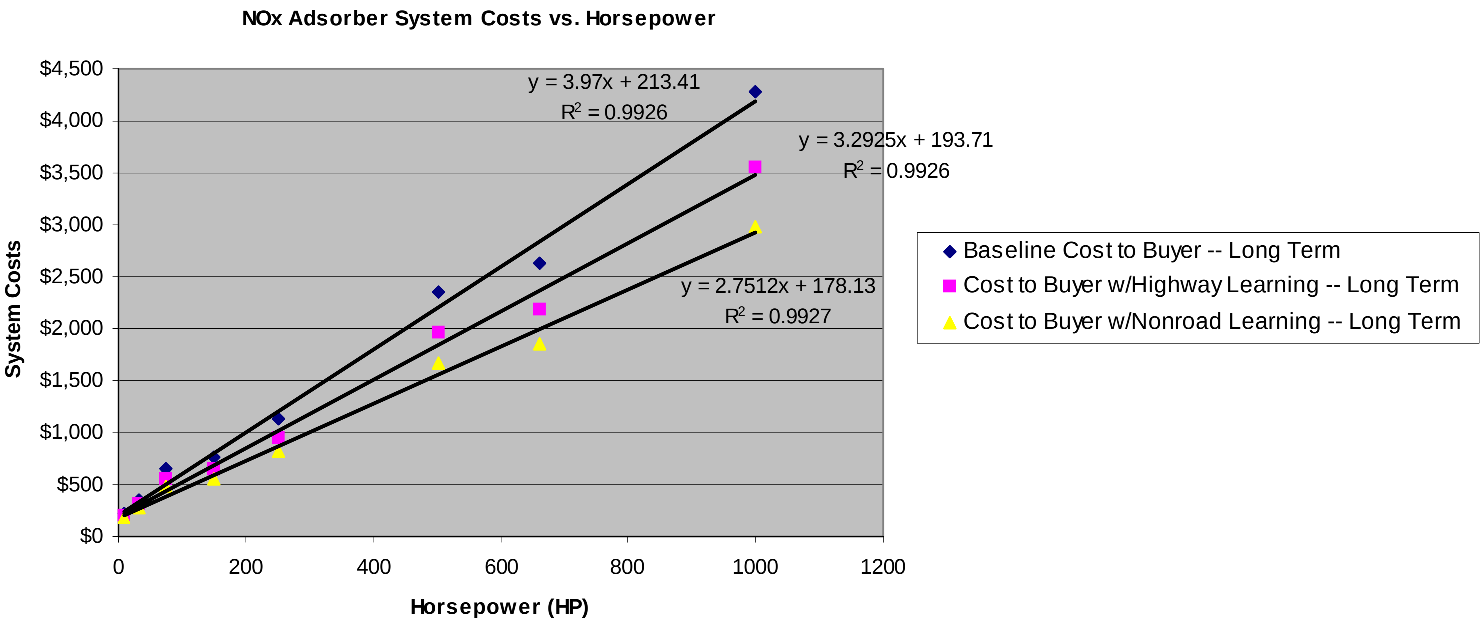
Table 3 presents a summary of the control costs associated with the NSPS for stationary CI engines that would be incurred due to emissions standards that are based on the use of both NOx adsorbers and CDPF. Note that in determining the combined control costs, the cost of an oxidation catalyst was excluded from the cost of the NOx adsorber since the CDPF include an oxidation catalyst element.

Table 3: Combined NOx Adsorber and CDPF Control Costs

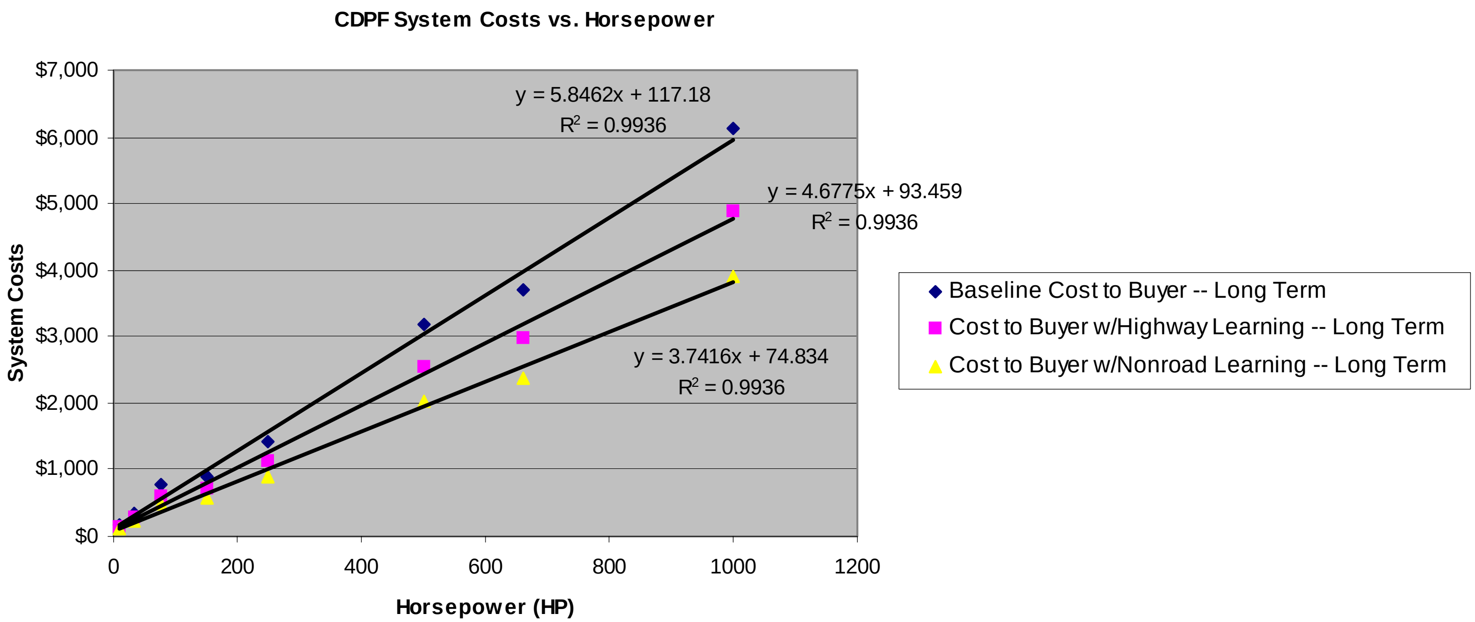
Engine Size (HP)	**Purchased Equipment Cost**	**Total Capital Cost**	**Total Annual Cost**		**Total Capital Cost ($/HP)**	**Total Annual Cost ($/HP)**	
			Prime	**Emergency**		**Prime**	**Emergency**
75	$809	$1,537	$242	$208	$20	$3	$3
135	$1,234	$2,345	$350	$317	$17	$3	$2
238	$1,963	$3,730	$524	$503	$16	$2	$2
400	$3,110	$5,909	$817	$796	$15	$2	$2
750	$5,588	$10,617	$1,473	$1,428	$14	$2	$2
3000	$21,518	$40,884	$5,587	$5,498	$14	$2	$2
				Average	**$16**	**$2**	**$2**

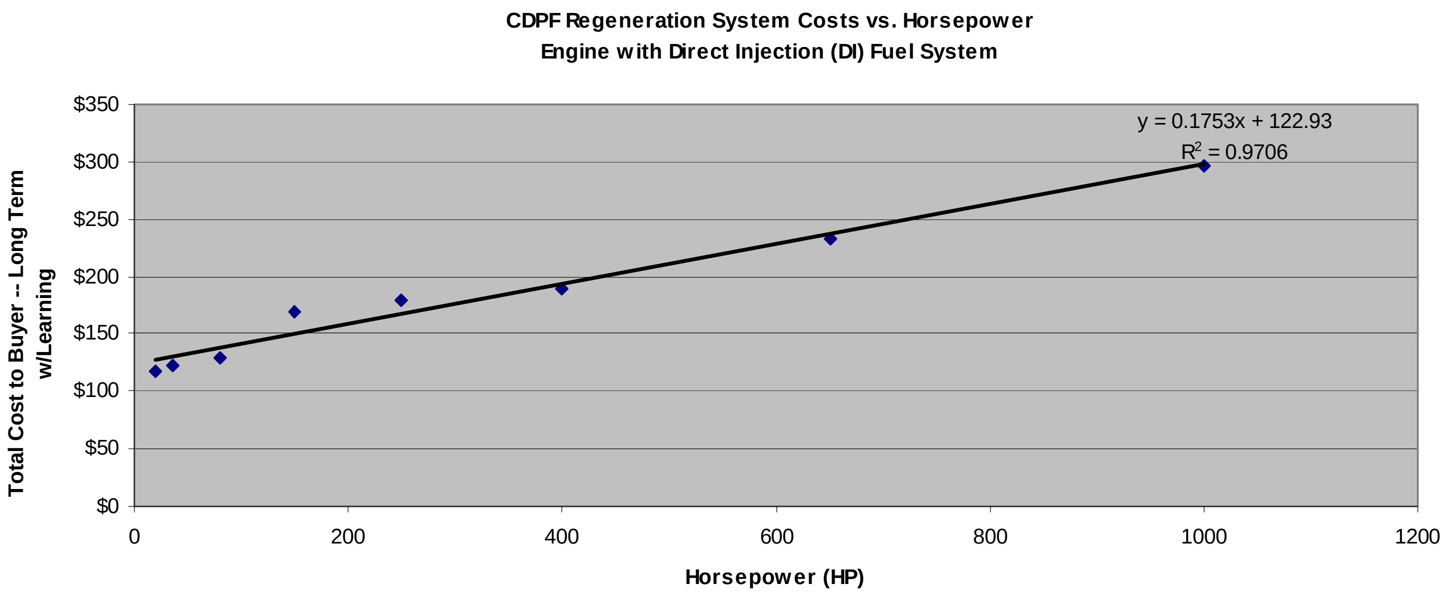
*Costs presented are based on the cost to buyer with nonroad learning.
**Costs do not include the cost of an oxidation catalyst element for NOx adsorbers.
***Costs presented include the cost of a regeneration system for engines with a DI fuel system.

Attachment A - Linear Regression Plots



NOx Adsorber System Costs vs. Horsepower
$4,500
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
System Costs
0
200
400
600
800
1000
1200
Horsepower (HP)
y = 3.97x + 213.41
R2 = 0.9926
y = 3.2925x + 193.71
R2 = 0.9926
y = 2.7512x + 178.13
R2 = 0.9927
Baseline Cost to Buyer -- Long Term
Cost to Buyer w/Highway Learning -- Long Term
Cost to Buyer w/Nonroad Learning -- Long Term


CDPF System Costs vs. Horsepower
System Costs
$7,000
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
0
200
400
600
800
1000
1200
Horsepower (HP)
y = 5.8462x + 117.18
R2 = 0.9936
y = 4.6775x + 93.459
R2 = 0.9936
y = 3.7416x + 74.834
R2 = 0.9936
Baseline Cost to Buyer -- Long Term
Cost to Buyer w/Highway Learning -- Long Term
Cost to Buyer w/Nonroad Learning -- Long Term


CDPF Regeneration System Costs vs. Horsepower
Engine with Direct Injection (DI) Fuel System
Total Cost to Buyer -- Long Term w/Learning
$350
$300
$250
$200
$150
$100
$50
$0
0
200
400
600
800
1000
1200
Horsepower (HP)
y = 0.1753x + 122.93
R2 = 0.9706