Economic Analysis and Feasibility of Cottonseed Oil as a Biodiesel Feedstock

FINAL REPORT

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Executive Summary

This research effort with the National Cottonseed Products Association in collaboration with PYCO, Incorporated is to investigate the costs of manufacturing cottonseed oil based biodiesel and test the performance characteristics for two cottonseed oil types. In the first phase of this project, a complex cost model has been developed to determine multiple financial characteristics of using cottonseed oil as a primary feedstock for biodiesel production. An executive summary of the cost model provides pertinent information which includes, total sales revenue, total annual manufacturing& logistics cost, manufacturing & logistics cost/gallon, total annual recovery cost, total capital investment, total annual labor cost, total annual raw material cost, total annual material handling cost, total annual utilities cost, and total annual miscellaneous costs associated with the production of cottonseed oil based biodiesel. A summary of the labor and energy costs by process is included as well.

The first cost model (Full Model) assumes that a biodiesel production facility must be constructed from the ground up, therefore, capital investment costs associated with the construction of a new plant facility are considered. An additional model (Special Oils) has been created to assume that the plant facility is already in place and there is no add-on capital cost of building a new facility. The biodiesel facility has the ability to blend in other oils in the biodiesel production process. Small cottonseed crushing operations with a production facility already in place can blend in various different oil types to produce the most cost efficient biodiesel.

The second phase of this research project tests the performance of two cottonseed oil types as blends of biodiesel added to typical low sulfur content diesel. Two oil types (PBSY and RBD) are used at two horsepower loads (20 and 60), one speed (1800 rpm), and four biodiesel blends (B_2, B_5, B_{10}, B_{20}). A total of 63 test runs are conducted (54 glass filter and 9 Teflon filter) creating 40,320 data points.

Statistical analysis of the data resulted in the following overall conclusions. RBD cottonseed oil outperformed PBSY oil on gaseous emissions for Nitrous Oxides and Carbon Monoxide. On average, RBD outperformed PBSY by 10% on the Carbon Monoxide gas emissions. PBSY and RBD are below the EPA emissions standards for Carbon Monoxide. RBD also outperformed PBSY on Nitrous Oxides emissions ranging 6% to 17% dependent upon the blend type (B_{20} = 17.55%). When the PBSY and RBD oil blends are compared with Diesel the blended biodiesel was within the EPA emissions standard for Nitrous Oxide. However, at the individual blend types some of the blends for both cottonseed oil types did exceed the allowable emissions for NOx. Therefore, from a cost standpoint it is more economically feasible to utilize PBSY cottonseed oil as a biodiesel feedstock. If emission standards are more stringent in some states and the selection criteria are based on quality of emissions, the RBD blend would be more applicable in that situation.

PHASE I

COST MODELING OF COTTONSEED OIL BASED BIODIESEL

1. Introduction

U.S. dependency on foreign oil supplies has increased with no real relief in sight for the near future. According to the Bureau of Transportation Statistics in 1960 the U.S. consumption of diesel fuel for transit highway use was 222 million gallons, which has grown to 768 million gallons in 2002. An additional 4068 million gallons is consumed in rail transportation annually. Alternative fuels such as agricultural based biodiesel could improve the situation from both economical and environmental stand points while not threatening the traditional product's market share.

Biodiesel is nontoxic, biodegradable, sulfur free and clean burning. It is considered to be a safe alternative fuel that has similar characteristics to traditional petroleum-based diesel fuel. Biodiesel can be formulated from any type of vegetable oil or used cooking oils. Biodiesel has an average Btu/lb rating of 17,000, depending on vegetable oil, vs. 19,340 Btu/lb for petroleum based diesel. This translates in little change in engine performance (torque and horsepower). Biodiesel is comprised of long chains of fatty acids (methyl-esters or ethyl-esters) that are oxygenated, which results in a higher flash point than that of conventional diesel. With a high flash point, biodiesel is safer to transport, and handle.

There has been much research on the economic feasibility of vegetable oils as a feed stock for biodiesel. To name a very few are the work by Ahousissoussi et.al. (1997), Bender, (1999), Knothe et. al (2005), Mittelbach (1996), Raneses et.al. (1999), Sonnino (1994), Dyne et.al. (1996). The general theme among these selected research studies indicates that there is a threshold of economic opportunity for the use of vegetable oils as a primary ingredient in bio-fuels. This research expanded on these research findings with a focused application on the use of cottonseed oil. In the past, edible-grade cottonseed oil held such a premium price and above average demand that the feasibility or cost/benefit was easy to calculate, and it was not a viable option. However, with recent events in the fuel cost an agricultural-based cottonseed biodiesel needs to be investigated.

It is estimated that there are approximately 790 lbs of seed per bale of cotton of which 44-46 gallons unrefined oil can be extracted per ton of cottonseed. According to the USDA, a total of 6.446 million tons of cottonseed was produced in 2003. Approximately 148.3 million gallons of biodiesel can be produced with only 50% of the total cottonseed. Cottonseed oil biodiesel could have the potential to create a more competitive oil market for producers, ginners, and oil mills. Moreover, creating such a product would help to reduce our dependency on foreign oil and utilize a renewable resource that is currently in production.

2. Research Objectives

The objective of this project is to create a representative cost model that can be used in later work to explore the cost feasibility of creating a biodiesel operation utilizing cottonseed oil from marketing, logistics, and manufacturing aspects. This will be accomplished by addressing the three key components in the following ways:

A. Market Related:

- Determine inventory and production requirements for both raw material and finished product to meet economic requirements. This will be accomplished through cost system analysis as well as simulation modeling.
- Establish capabilities to model manufacturing per unit cost ($ per gallon) through cost system analysis and modeling tools.

B. Logistics:

- Determine the economic cost associated with transportation for the raw materials. This will be accomplished through cost system analysis and simulation modeling based on current freight rates. Sensitivity to freight cost and mode of transportation availability will be examined. The logistics and supply chain analysis utilized the Center for Engineering, Logistics, and Distribution (CELDI) program at Texas Tech University.

C. Manufacturing:

- The oil mill process was examined to determine the most economical processing to produce a cottonseed oil that meets the requirements for biodiesel as compared to their current product lines.
- A comprehensive cost system was developed that can be used to determine machine and labor compliments required. It was also used to examine economic sensitivity issues such as: sensitivity to raw material availability, capital equipment cost, productivity, transportation cost, labor cost, selling price, and the effect on oil mill by-products when producing biodiesel, etc.

3. Methods

A Cost Model of this type of project is complex and includes several interdependent variables. The evaluation and analysis of the different variables has been divided into five different project tasks. A description of each one of the tasks to be performed during the Phase I of the project is presented below:

Task 1. Procurement of Production Specifications

Establish model with the capabilities to estimate oil mill manufacturing requirements for producing a cottonseed oil based biodiesel.

The model should improve the capability to perform a comprehensive analysis of the cottonseed oil mill manufacturing process as it relates to biodiesel and the processing of co-products such as cottonseed cake, glycerin, glycerin bottoms, soluble potash and soaps.

Task 2. Determine raw material availability

The information that will be obtained and compared for estimating purposes will be units of raw material required, unit cost and the quality criteria for acceptance. Information on location of the available raw material sources will also be included.

Task 3. Determine desired or required biodiesel production capacity.

The model will allow the exploration of varied production rates taking into consideration capital cost, labor cost, raw material cost, transportation cost, product demand timeframe, and overhead cost.

Task 4. Determine logistical requirements.

Transportation costs are critical to the total cost of the product. The model will be used to model estimated transportation cost and used to perform sensitive analysis to a change in hauling cost.

Task 5. Develop comprehensive cost system for proposed biodiesel operation.

The cost system for this type of project will be complex with many interdependent variables. The project was approached from the standpoint of whether or not it was worthy of capital investment

4. Analysis and Results

Two basic software tools were utilized for developing the cost model, Microsoft Excel and Crystal Ball 2000 (Decisioneering, Denver, CO). The spreadsheet included linked organized data and formulas that were necessary to complete the model. Crystal Ball 2000 was used as the simulation software and it was applied to assign statistical distributions to the independent variables and prediction variables for decision analysis and forecasting. A free examination copy of Crystal Ball is available at: http://www.decisioneering.com/, under menu topic "Products". The attached model can only be opened if Crystal Ball is opened first. The general appearance will be as an Excel worksheets with a Crystal Ball menu line added.

The developed model includes several key and interdependent elements such as: production capacity, raw material availability, in-plant trucking, storage, operation cost, revenue, depreciation, labor, utilities, capital investment, and overhead cost. Each element of the model will be briefly discussed in the following:

When appropriate, Crystal Ball analysis was used to apply a distribution to a variable to improve the predictive properties of the model. This was denoted by a "**CB"** designation after an item. Listings of the distributions utilized are contained in Table 1.

It should be noted that the examples used the following sections were populated with estimated values. Therefore, no specific inference should be taken on the values.

The model took into consideration that each operation will be specific and the values utilized will not be appropriate for all locations and end users.

Table 1. Statistical Characteristics of the Cost Model Variables

Variable	Distribution	Units	Distribution Parameters	Range
Methanol cost/gallon	Triangular	$/gal	Min. = $1.50; Max. = $3.00; Likeliest = $2.25	
Biodiesel(gal.) per ton of cottonseed	Normal	Gal.	Mean = 42; Std. Dev. = 2	42 - 44
Cottonseed cost/ton	Triangular	$	Min. = $100; Max. = $170 Likeliest = $157.50	
Hauling distance from farm	Normal	Miles	Mean = 250; Std. Dev. = 10	240 -270
Average truck distance used per year	Normal	Miles	Mean = 500; Std. Dev. = 50	450 -550
Natural Gas Used	Normal	MMBTU	Mean = 439,719; Std. Dev. = 5000	435,000 – 445,000
Natural Gas Contract Amt.	Triangular	$	Min. = $4.23; Max. = $5.89 Likeliest = $5,03	
Cotton meal amt. produced/year	Triangular	Gal.	Min. = .04; Max. = .08 Likeliest = .06	
Cotton meal recovery cost/unit	Normal	$	Mean = $.10; Std. Dev. = $.01	
Seed Hull amt. produced/year	Triangular	Gal.	Min. = .04; Max. = .08 Likeliest = .06	
Seed Hull recovery cost/unit	Normal	$	Mean = $.10; Std. Dev. = $.01	
Linters amt. produced/year	Triangular	Gal.	Min. = .04; Max. = .08 Likeliest = .06	
Linters recovery cost/unit	Normal	$	Mean = $.10; Std. Dev. = $.01	
Tax incentive recovery cost/unit	Normal	$	Mean = $.48; Std. Dev = $.10	$.38 - $.58

A. Executive Summary Sheet

The executive summary section of the model gives an estimate of the annual revenues and costs associated with the production of a specific amount of biodiesel. The executive summary section includes:

- Total Annual Sales Revenue
- Total Annual Manufacturing & Logistics Cost
- Manufacturing & Logistics cost per gallon of BD
- Total Annual Recovery Cost
- Total Capital Investment
- Total Annual Labor Cost
- Total Annual Raw Material Cost
- Total Annual Material Handling Cost
- Total Annual Utilities Cost
- Total Annual Miscellaneous Cost

Within each section, there is a breakdown on how the annual cost or revenue is accumulated. For a more in depth look, each part was broken down into its own section along with its associated costs and revenues. The numbers in the table below are associated with a 10,000,000 gallon biodiesel production plant. The following tables are examples of the type of information contained in the Executive Summary section. Table 2 summarizes the many cost centers with a calculated cost of producing a gallon of biodiesel with the entered parameters.

Table 2: Summary Section for the Biodiesel Cost Model a Texas Tech Student Organization deposits $2000 each year into an account that earns interest at a rate of 8.0% compounded quarterly. What is the amount in the account at the end of 5 years if after the first year you increase each following year by $50

	Yearly Production Capacity of BD (gallon)		10,000,000
	Total Annual Sale Revenue		**$34,500,000.00**
	Total Annual Recovery Cost		$5,268,343.92
	Total Capital Investment Cost		$9,229,860.00
	Total Annual Manufacturing & Logistics Cost		**$44,545,873.13**
	- Total Annual Fixed Cost		$3,581,146.66
	- Total Annual Variable Cost		$40,964,726.47
	Manufacturing & Logistics Cost per Gallon of BD		**$4.45**

After the summary section the model is broken down into individual cost and revenue generators. These sections are illustrated with tables 3 and 4.

Table 3. Recovery Costs

Production Capacity	
Yearly Production Capacity of BD (gallon)	10,000,000
Sale Price per Gallon	$3.45
Total Annual Sale Revenue	**$34,500,000.00**
Recovery Cost	
Total Annual Recovery Cost of Cotton meal (cake)	$10,515.64
- Amount Produced (Ton) per Ton of Cottonseed	16,748.17
- Recovery Cost per Ton	$0.63
Total Annual Recovery Cost of Seed hulls	$5,457.71
- Amount Produced (Ton) per Ton of Cottonseed	11,313.91
- Recovery Cost per Ton	$0.48
Total Annual Recovery Cost of Linters	$7,562.37
- Amount Produced (Ton) per Ton of Cottonseed	17,180.36
- Recovery Cost per Ton	$0.44
Total Annual Recovery Cost of Tax incentives	$5,244,808.20
Tax Incentives Cost per Gallon of BD	$0.52
Total Annual Recovery Cost	**$5,268,343.92**
Capital Investment	
Total Building Investment Cost	$150,000.00
Total Machinery Investment Cost	$9,079,860.00
Total Capital Investment	**$9,229,860.00**

Labor Cost	
Total Annual Direct Labor Cost	$407,040.00
- Total Cost per Day of Shift I - Day Shift	$768.00
- Total Cost per Day of Shift II - Night Shift	$1,743.40
Total Annual Indirect Labor Cost	$924,000.00
- Total Cost per Day of Shift I - Day Shift	$768.00
- Total Cost per Day of Shift II - Night Shift	$1,743.40
Total Annual Labor Cost	**$1,331,040.00**

Table 4. Raw Material

Raw Material Cost	
1. Total Annual Cottonseed & Hauling Cost	$40,414,782.67
Yearly Cottonseed Required (Ton)	258,767.07
Cottonseed Cost per Ton	$157.50
Total Annual Hauling Cost	$4,162,858.87
2. Total Annual Solvent Extraction Cost	$20,000.00
3. Total Annual Methanol Cost	$4,500,000.00
Total Annual Raw Material Cost	**$44,934,782.67**
In-Plant Material Handling	
No. of In-Plant Trucks	20
1. Total Annual Fixed Cost	$3,990.00
2. Total Annual Variable Cost	$355.19
Total Variable Cost per Mile	$0.7593
Average distance used per year	467.78
3. Total Annual Driver Labor Cost	$36,000.00
Total Annual Material Handling Cost per Truck	$4,345.19
Total Annual Material Handling Cost	**$122,903.80**

Utilities Cost	
Total Annual Electric Cost	$128,790.00
Total Annual KWH used	1,431,000.00
Cost per KWH	$0.09
Total Annual Natural Gas Cost	$2,356,053.16
Total Annual MMBTU used	446,457.06
Contract Price per MMBTU	$5.28
Total Annual Maintenance Cost	$136,197.90
Total Annual Overhead Cost	$6,105.60
Total Annual Utilities Cost	**$2,627,146.66**
Miscellaneous Cost	
Total Annual Property Insurance	$25,000.00
Total Annual Office Supplies	$5,000.00
Total Annual Miscellaneous Cost	**$30,000.00**

Labor cost and utility consumption is also included in the labor section of the Executive Summary worksheet. Table 5 is broken down into the main function groups of the operation.

Table 5. Labor Summary Table

		Annual Labor Cost			**Annual Electric Consumption**	
No.	**Process**	**Direct**	**Indirect**	**Total Cost**	**KHW Used**	**Total Cost**
1	Cleaning Room	$192.00	$792.45	$984.45	238,500.00	$21,465.00
2	Lint Room	$192.00	$0.00	$192.00	265,000.00	$23,850.00
3	Bale Press	$96.00	$566.04	$662.04	424,000.00	$38,160.00
4	Huller Room	$192.00	$0.00	$192.00	0.00	$0.00
5	Prep & Flake	$192.00	$0.00	$192.00	0.00	$0.00
6	Solvent Extraction	$96.00	$679.25	$775.25	0.00	$0.00

7	Refined	$96.00	$905.66	$1,001.66	0.00	$0.00
8	Bleached	$96.00	$0.00	$96.00	265,000.00	$23,850.00
9	Deodorized	$96.00	$0.00	$96.00	0.00	$0.00
10	Methyl Ester Plant	$288.00	$543.40	$831.40	238,500.00	$21,465.00

B. Input data

The input data section of the model contains the following:

- Production capacity in gallons. (CB)
- Raw material transportation cost (CB)
- Methanol consumption and cost (CB)
- Days of operation per year
- Production hours per day
- Tax rate
- Insurance
- Sale price gallon of biodiesel (CB)

In the input section the model allows the user to vary critical production parameters. This flexibility allows for the model to be modified with a minimum amount of effort. It also will allow for later sensitivity analysis of critical parameters. Examples are contained in Tables 6,7, and 8.

Table 6. Model Input Section (Production Capacity)

Production Capacity					
	Yearly Production Capacity of BD (gal.)	10,000,000			
	Sale Price per Gallon	$3.45			
Raw Material					
1	Gallon of BD Produced per Ton of Cottonseed	42			
2	Cottonseed Cost per Ton ($)	$157.50	In West Texas at 07/2006 - Range of $140-260/ton		
3	Hauling Distance from Cotton Gin to Mill (mile)	250.00			
4	Cottonseed Hauling Cost (per mile)	$1.40		per mile	
5	Cottonseed Truck Capacity (ton)	22		per truck	
6	Annual Cost of Solvent extraction ($)	$20,000.00			
7	Methanol required	2,000,000.00		20% methanol with no recovery at this point	0.2
	Catalyst required	285,000.00		lbs of catalyst NaOH per gallon of oil (pass #1)	0.0285
		213,750.00	(.75 of 1st pass)	lbs of catalyst NaOH per gallon of oil (pass #2)	0.021375

Table 7. Model Input Section (Raw Material Logistics)

Raw Material Cost				
	Methanol cost	$4,500,000.00	methanol cost per gallon	$2.25
	Catalyst cost 1st Pass	$270,750.00	NaOH cost per pound	$0.95
	Catalyst cost 2nd Pass	$203,062.50		
In-Plant Truck				
8	Truck Investment Cost ($)	$100,000.00		
9	No. of in-plant Trucks	20	22-ton Trucks	
10	Labor Cost of a Truck Driver per Year	$18,000.00		
11	Number of Truck Drivers	2		
12	Gas Fuel Cost (per gallon)	$2.94		
13	Average Distance Used per Year (mile)	500.00	Standard Deviation of 50 mile	

Table 8. Model Input Section (Cost Recovery)

Cost Recovery			
14	Amount Produced (ton) per Ton of Cottonseed		
	1. Cotton Meal (cake)	0.06	Range of 4-8% or 0.04-0.08
	2. Seed Hulls	0.06	Range of 4-8% or 0.04-0.08
	3. Linters	0.06	Range of 4-8% or 0.04-0.08
15	Recovery Cost per Ton ($)		
	1. Cotton Meal (cake)	$0.10	Standard Deviation of $0.01
	2. Seed Hulls	$0.10	Standard Deviation of $0.01
	3. Linters	$0.10	Standard Deviation of $0.01
16	Tax Incentives Cost per Gallon of BD	$0.28	Standard Deviation of $0.01
Operation Process			
17	No. of working days in one operation year	265	For Direct Labor and Electric Machinery Cost
			If more than 2 shifts, add another shift table in "Labor"
18	No. of shifts in a Day	2	worksheet
19	Property Insurance Cost per Year ($)	$25,000.00	
20	Office Supplies Cost per Year ($)	$5,000.00	
21	Cost per KWH of Machinery ($)	$0.09	
22	Total Amount Used of Natural Gas (MMBTU)	439,719.00	
23	Contract Amt of Natural Gas ($)	$5.03	Range of 4.23 min and 5.89 max
	Allocation Cost of Maintenance Cost per		
24	Machinery Cost (%)	1.50%	
	Allocation Cost of Overhead Cost per Direct		
25	Labor Cost (%)	1.50%	

C. Cotton Seed Cost

Cotton seed grade is directly related to oil yield and the price per ton paid for the raw material. The model has the capability to vary the quality grade to adjust oil yield (CB) and cost (CB). This in turn will adjust the raw material required to meet production requirements. Other critical cost centers such as transportation will also adjust accordingly. Table 9 illustrates the parameters that have been assigned distributions. (Refer to Table 1).

Table 9. Input Parameters for Cotton Seed

Input			Output	
Yearly Production Capacity (Gallon)	10,000,000.00		Yearly Cottonseed required (Ton)	245,221.46
BD (Gallon) per Ton of Cottonseed	40.78		Total Annual Cottonseed Cost ($)	$40,463,462.17
Cottonseed Cost per Ton ($)	$165.01			
Hauling Distance from Farm (mile)	242.93		Number of truck loads	11,147
Cottonseed Hauling cost (per mile)	$1.40		Total Annual Hauling Cost	$3,791,153.60
Cottonseed Truck Capacity (ton)	22.00		**Total Annual Cost**	**$44,254,615.70**

D. Capital Investment

The investment section of the model includes three different production scenarios. To improve versatility, the model will include small, medium, and large capacity plant configurations. Depending on the annual production capacity and the days of operation entered into the Input section, the model will select the appropriate size operation to meet the production requirements. The Investment section will include the following:

- Machinery complement appropriate for production capacity required (small, medium, large)
- Building
- Land
- Permitting (state, federal)

E. Material Handling

Material handling will be dependent on the size of the operation. The model will include the following:

- Cost associated with the use of on sight hauling (CB)
- Fuel cost (CB)
- Front end loaders
- Maintenance
- Insurance, inspection, and licensing of the trucks
- Labor costs associated with the truck usage

This section is separated into three parts:

- Fixed Operating Costs
- Variable Operating Costs
- Labor Costs

F. Labor

The model allocated costs associated with the direct and indirect costs of labor. The labor was separated by a small, medium, or large sized production process and then by the two shifts. The model includes the costs specific to each production process and the ability to vary the number of regular and overtime laborers, working hours, rates/hour, and the rates/year. Table 10 is an example of how the direct and indirect labor costs were summarized.

Table 10. Direct & Indirect Labor Cost Assignments

Total Direct Cost per Day	$1,536.00
Total Indirect Cost per Day	$3,486.79
Total Labor Cost per Day	**$5,022.79**
Total Direct Cost per Year	$407,040.00
Total Indirect Cost per Year	$924,000.00
Total Labor Cost per Year	**$1,331,040.00**

G. Utilities

The model will include a breakdown of costs associated with the production process. This will be dependent on the size of the operation and the associated machinery complement. The costs associated with the production process include:

- Annual Power Consumption
    - Electric - (KWH used/year) & Total Cost
    - Natural Gas – (MMBTU used), Contract Amount, & Total Cost
- Annual Maintenance Cost
- Annual Overhead Cost

H. Cost Recovery

The proposed operation will not only manufacture biodiesel it will also provide a revenue stream based on the bi-products produced during the process. The model will include the following elements:

- Biodiesel(CB)
- Cotton seed meal(CB)
- Seed hulls(CB)
- Linters(CB)

The sections in green were given specific distributions and parameters using the Crystal Ball software and they can be found in Table 1. Table 11 illustrates the summary section for the Cost Recovery worksheet. It should be noted that the value in Table 11 may not match other worksheets that were generated during different phases of the model and is just formatting and presentation purposes.

Table 11. Cost Recovery Summary Sheet

No.	Item	Amount Produced per year	$Recovery Cost/Unit	Total Annual Recovery Cost
1	Cotton meal (cake)	17,196.11	$0.10	$1,720
2	Seed hulls	11,343.96	$0.10	$1,134
3	Linters	16,432.05	$0.10	$1,643
	Total Cost per Year			**$4,497**

I. Depreciation

The model includes provisions for the use of different types of depreciation depending on the requirements of the customer. The yearly values for the different sized production processes depended on the quantity of BD produced and then on the specific values given for the small, medium, and large production processes stated earlier. The model includes an individual section for the machinery and also the building. Tables 12 and 13 give examples of the tables used to calculate the depreciation by classification.

Table 12. Depreciation Schedules for Capital Equipment

Machinery Investment

Source: IRS Publication 946 - How to Depreciate Property, 2005, 7-years recovery period, Table A-1

Year	MACRS Depreciation Rate	Scenario		
		Small-Size	Medium-Size	Large-Size
Estimated Total Machinery Investment Cost ($)		**$389,577.50**	**$3,052,620.00**	**$9,079,860.00**
1	14.29%	$55,670.62	$436,219.40	$1,297,511.99
2	24.49%	$95,407.53	$747,586.64	$2,223,657.71
3	17.49%	$68,137.10	$533,903.24	$1,588,067.51
4	12.49%	$48,658.23	$381,272.24	$1,134,074.51
5	8.93%	$34,789.27	$272,598.97	$810,831.50
6	8.92%	$34,750.31	$272,293.70	$809,923.51
7	8.93%	$34,789.27	$272,598.97	$810,831.50
8	4.46%	$17,375.16	$136,146.85	$404,961.76

Table 13. Depreciation Schedule for Facilities

Building Investment

Source: IRS Publication 946 - How to Depreciate Property, 2005, 39-years recovery period, Table A-7a

** Assume 1 month property placed in service

Year	MACRS Depreciation Rate	Scenario		
		Small-Size	Medium-Size	Large-Size
Total Building Investment Cost ($)		**$20,000.00**	**$75,000.00**	**$150,000.00**
1	2.461%	$492.20	$1,845.75	$3,691.50
2-39	2.564%	$512.80	$1,923.00	$3,846.00
40	0.107%	$21.40	$80.25	$160.50

5. Summary

All of the pertinent data was included on a summary page. This allows for the breakdown and viewing of costs associated with the project at any one point, which include:

- Total Annual Fixed Cost
- Total Annual Variable Cost
- Total Annual Recovery Cost
- Total Annual Operating Cost

Table 14 and 15 summarize the fixed and variable cost for the model.

Table 14. Total Annual Fixed Cost

No.	Item	Annual Cost
1	Indirect Cost	$924,000.00
2	Property Insurance Cost	$25,000.00
3	Electricity Cost	$128,790.00
4	Natural Gas Cost	$2,300,353.91
5	Maintenance Cost	$136,197.90
6	Overhead Cost	$6,105.60
7	Office Supplies	$5,000.00
	Total Annual Fixed Cost	**$3,525,447.41**

Table 15. Total Annual Recovery and Operating Costs

No.	Item	Annual Cost
1	Direct Cost	$407,040.00
2	Raw Material	
	2.1 Cottonseed	$49,927,093.58
	2.2 Solvent extraction	$20,000.00
	2.3 Methanol	$4,500,000
3	Cotton Seed-Hauling Cost	$3,703,647.59
4	In-Plant Material Handling	$122,504.57
	Total Annual Variable Cost	**$58,680,285.75**
Annual Sale Revenue		**$34,500,000.00**
Total Annual Recovery Cost		**$5,390,703.59**
		$39,890,703.59
Total Annual Operating Cost		**$62,242,945.08**
Total Cost		**-$22,352,241.49**

This section in the model includes the machinery and building investment costs associated with a small, medium, or large sized production process. There are specific machines that perform certain processes and the model gives the different investment costs for each one along with the following:

- Quantity
- KWH
- Hr used/day
- Total KWH used/day
- Investment Cost

Table 16 contains an example of how the model can be populated with actual quotes or best estimates that meet the need of the user.

Table 16. Equipment Selection and Allocation Summary Sheet

Scenario 3: Large-Size Production						
Process No.	**Building/Mach.**	**Q**	**KWH**	**Hr Used/ Day**	**Total KWH Used/Day**	**Investment Cost**
Machinery Investment						
1	Equipment A	3	15.00	20	900.00	$10,000.00
2	Equipment B	2	25.00	20	1000.00	$10,000.00
3	Equipment C	1	35.00	20	700.00	$10,000.00
4	Equipment D	0	45.00	20	0.00	$10,000.00
5	Equipment E	0	55.00	20	0.00	$10,000.00
3	Equipment F	1	45.00	20	900.00	$10,000.00
7	Equipment G	0	35.00	20	0.00	$10,000.00
8	Equipment H	2	25.00	20	1000.00	$10,000.00
9	Equipment I	0	25.00	20	0.00	$10,000.00
10	Equipment J	3	15.00	20	900.00	$2,996,620.00
Building Investment						
	Building A	2				$30,000.00
	Building B	1				$30,000.00
	Building C	2				$30,000.00
	Building D	0				$30,000.00

A. Cash Flow

The model was used to show the cash flows for a specific quantity of BD produced over a certain time span. For each year, the model developed cash flows for the following:

- Revenue
- Operating Cost
- Recovery Cost
- Building Investment
- Machinery Investment

Using the cash flows for the parts above, a cash flow for the total amount cash for the production process of each year was created. It shows the amount of cash the production process will accumulate each year.

6. Model 2: Utilizing Oil Only

An alternate model was included so that interested parties that were purchasing oil or currently manufacturing oil would be able to utilize the features. The alternate model also allow for blending different oils or oils at different points in the refining process. In the following table the allowance for blends is illustrated.

Table 17. Special Oil Blending for Cost Control

	%Oil #1	%Oil #2	%Oil #3	Total
	0.00%	0.00%	0.00%	100.00%
Oil $/Lbs	$0.00	$0.00	$0.00	
lbs/gal	7.6	7.8	7.5	
Blend $/gal	$0.00	$0.00	$0.00	$0.00

PHASE II

PERFORMANCE TESTING OF COTTONSEED OIL BIODIESEL BLENDS

1. RESEARCH METHODOLOGY

This phase of the project will focus on the data collection of performance characteristics of biodiesel. The experiment will consist of a diesel engine dynamometer coupled with a diesel engine that is used in typical agricultural use. The performance parameters that are of interest are exhaust emissions and engine torque/horsepower curves from cotton-based biodiesel. The analysis will be conducted using various blends of biodiesel (B0, B2, B5, B10, and B20) against petroleum-based diesel measuring the parameters previously mentioned. These parameters are chosen specifically for their impact on overall engine performance. In the performance analysis along with an economical evaluation of each blend will be observed in comparison to petroleum-based diesel fuel.

1. Couple provided diesel engine with suitable engine dynamometer.
2. Perform parameter test with pure petroleum distillate as control for overall experiment.
3. Perform parameter test with splash blended and neat cotton seed based biodiesel.
4. Record all data in preparation for analysis with cost considerations.
5. Using statistical analysis determine the performance characteristics for cottonseed oil methyl-ester blends.

6. Identify the preferred cottonseed oil type, from a cost perspective, to be used as a biodiesel blend.

The parameters that will be monitored are nitrous oxides, sulfur dioxide, carbon monoxide, carbon dioxide, horsepower, and torque. The experiment is laid out in a 9 x 2 x 1 x 3 randomized design with 9 treatments, two loads (20 and 60 hp), one speed (1800 rpm), and three replications totaling 54 test runs. Each test run is four minutes long with data collected every 3 seconds. All treatments are replicated three times for robust statistical data analysis obtained from the average value of the collected data. These test cycles will be repeated for all of the various blends of biodiesel and also with petroleum distillate as the control.

The equipment used for this test experimentation is a 5.9L Cummins diesel engine coupled with a Stuska Dynamometer. A two bank design collection system (on loan from the United States Department of Agriculture, Cotton Ginning Research Lab) for emissions is used to collect particulate matter from each test run. The collection system consists of two filter transitions each containing one tray which holds four glass fiber filters. An ECOM A-PLUS gas analyzer is used for the engine emissions analysis. A Kurtz Series 2440 Portable Hot Wire Anemometer is used to collect temperature readings at the outlet side of the engine exhaust system and at the inlet port to the dual filter trays.

2. Data Analysis

Emission results of PBSY v/s RBD at different blends on 20 and 60 HP engine

2.1 PBSY Vs RBD - Complete Data (20 HP / 60 HP)

Complete Data (20 HP)

In table 2.1.1 below, the probability values of all the gases are less than 0.05 (Please refer the circles in green color.) hence we check for unequal variances in two sample t-test.

Table 2.1.1 Equality of Variance

Equality of Variances

Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	662	560	1.38	<.0001
CO	Folded F	662	560	1.36	0.0002
NO	Folded F	560	662	1.54	<.0001
NO2	Folded F	662	560	1.24	0.0093
NOx	Folded F	560	662	1.42	<.0001
SO2	Folded F	662	560	.	.
CO2	Folded F	662	560	1.24	0.0073

From the table 2.1.2 below titled two sample t-tests we can say that all the gases other than CO and CO_2 have a significant effect on PBSY and RBD and hence we check for the table of statistics. (Refer Appendix A, Table 1).

Table 2.1.2 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	1222	-3.66	0.0003
O2	Satterthwaite	Unequal	1222	-3.71	0.0002
CO	Pooled	Equal	1222	-1.88	0.0610
CO	Satterthwaite	Unequal	1222	-1.90	0.0578
NO	Pooled	Equal	1222	-7.55	<.0001
NO	Satterthwaite	Unequal	1071	-7.42	<.0001
NO2	Pooled	Equal	1222	-8.89	<.0001
NO2	Satterthwaite	Unequal	1217	-8.97	<.0001
NOx	Pooled	Equal	1222	-8.59	<.0001
NOx	Satterthwaite	Unequal	1098	-8.47	<.0001
SO2	Pooled	Equal	1222	.	.
SO2	Satterthwaite	Unequal	1222	.	.
CO2	Pooled	Equal	1222	1.52	0.1292
CO2	Satterthwaite	Unequal	1218	1.53	0.1257

Referring to table 1 from Appendix A, we can say that for complete data emission content of O_2, NO, NO_2, NO_X is more in case of emission of RBD than that of PBSY. However, content of other gases like CO, CO_2 in emission is more in case of emissions of PBSY than that of RBD.

Complete Data (60 HP)

Using table 2.1.3 below, the probability values of gases like O_2, CO, NO are less than 0.05 (Please refer the circles in green color). Therefore, we check for unequal variances in two sample t test and the probability values of NO_2, NO_x, SO_2, CO_2 are greater than 0.05 (Please refer circle in red color). And, we check for equal variances in two sample t-test.

Table 2.1.3 Equality of Variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	641	611	1.46	<.0001
CO	Folded F	611	641	2.07	<.0001
NO	Folded F	611	641	3.09	<.0001
NO2	Folded F	611	641	1.05	0.5492
NOx	Folded F	611	641	1.05	0.5518
SO2	Folded F	611	641	1.11	0.1822
CO2	Folded F	611	641	1.05	0.5514

From the table 2.1.4 below titled two sample t-tests we can say that gases like CO, NO, O_2 have a significant effect on PBSY and RBD and also check for the table of statistics. (Refer Appendix B, Table 1).

Table 2.1.4 Two Sample t-test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	1252	-4.94	<.0001
O2	Satterthwaite	Unequal	1228	-4.96	<.0001
CO	Pooled	Equal	1252	5.01	<.0001
CO	Satterthwaite	Unequal	1085	4.97	<.0001
NO	Pooled	Equal	1252	8.27	<.0001
NO	Satterthwaite	Unequal	959	8.17	<.0001
NO2	Pooled	Equal	1252	0.03	0.9732
NO2	Satterthwaite	Unequal	1246	0.03	0.9732
NOx	Pooled	Equal	1252	0.21	0.8337
NOx	Satterthwaite	Unequal	1246	0.21	0.8338
SO2	Pooled	Equal	1252	-0.26	0.7944
SO2	Satterthwaite	Unequal	1239	-0.26	0.7947
CO2	Pooled	Equal	1252	0.10	0.9225
CO2	Satterthwaite	Unequal	1246	0.10	0.9225

Referring to table 1 from Appendix B, we can say that for complete data emission content of O_2 is more in case of emission of RBD than that of PBSY. However, contents of other gases like CO, NO in emission are more in case of emissions of PBSY than that of RBD.

The comparative emission results of PBSY and RBD for 20 HP and 60 HP are summarized in the table below:

Oils compared	**Blend**	**Gases in Emission**	**20 HP**	**60 HP**
PBSY Vs RBD	Complete Data	O_2	no difference in results	more effect on RBD
		CO		more effect on PBSY
		NO		more effect on PBSY
		NO_2		no difference in results
		NO_X		no difference in results
		SO_2		NA
		CO_2		no difference in results

2.2 PBSY Vs RBD – Blend B2 (20 HP / 60 HP)

At B2 (for 20 HP)

Using table 2.2.1 below, the probability values of all gases are greater than 0.05 (Please refer the circles in red color). Hence, we check for equal variances in two sample t test.

Table 2.2.1 Equality of variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	2	2	4.51	0.3627
CO	Folded F	2	2	1.33	0.8582
NO	Folded F	2	2	2.51	0.5699
NO2	Folded F	2	2	1.12	0.9452
NOx	Folded F	2	2	1.96	0.6750
SO2	Folded F	2	2	.	.
CO2	Folded F	2	2	3.05	0.4938

From the table 2.2.2 below titled two sample t-tests we can say that there is no significant difference between PBSY and RBD, therefore, we do not check for the table of statistics.

Table 2.2.2 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	4	-0.43	0.6911
O2	Satterthwaite	Unequal	2.84	-0.43	0.6994
CO	Pooled	Equal	4	0.55	0.6093
CO	Satterthwaite	Unequal	3.92	0.55	0.6099
NO	Pooled	Equal	4	1.11	0.3300
NO	Satterthwaite	Unequal	3.38	1.11	0.3405
NO2	Pooled	Equal	4	0.58	0.5946
NO2	Satterthwaite	Unequal	3.99	0.58	0.5946
NOx	Pooled	Equal	4	0.93	0.4030
NOx	Satterthwaite	Unequal	3.62	0.93	0.4081
SO2	Pooled	Equal	4	.	.
SO2	Satterthwaite	Unequal	4	.	.
CO2	Pooled	Equal	4	0.31	0.7738
CO2	Satterthwaite	Unequal	3.18	0.31	0.7775

At B2 (for 60 HP)

Using table 2.2.3 below, the probability values of gases like O_2, CO, NO are less than 0.05 (Please refer the circles in green color). Hence we check for unequal variances. Whereas, the probability values of NO_2, NO_x, SO_2, and CO2 are more than 0.05 (Please refer the circles in red color) we check for equal variances in two sample t test.

Table 2.2.3 Equality of variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	152	152	2.58	<.0001
CO	Folded F	152	152	2.25	<.0001
NO	Folded F	152	152	10.69	<.0001
NO2	Folded F	152	152	1.00	0.9999
NOx	Folded F	152	152	1.00	0.9940
SO2	Folded F	152	152	1.11	0.5058
CO2	Folded F	152	152	1.00	0.9973

From the table 2.2.4 below titled two sample t-tests we can say that gases O_2, CO, NO have significant impact on PBSY and RBD and whereas gases like NO_2, NO_x, SO_2, and CO_2 have significant impact on PBSY.

Table 2.2.4 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	304	-2.89	0.0041
O2	Satterthwaite	Unequal	254	-2.89	0.0041
CO	Pooled	Equal	304	4.23	<.0001
CO	Satterthwaite	Unequal	265	4.23	<.0001
NO	Pooled	Equal	304	7.18	<.0001
NO	Satterthwaite	Unequal	180	7.18	<.0001
NO2	Pooled	Equal	304	0.00	0.9992
NO2	Satterthwaite	Unequal	304	0.00	0.9992
NOx	Pooled	Equal	304	0.08	0.9391
NOx	Satterthwaite	Unequal	304	0.08	0.9391
SO2	Pooled	Equal	304	0.04	0.9695
SO2	Satterthwaite	Unequal	303	0.04	0.9695
CO2	Pooled	Equal	304	0.03	0.9755
CO2	Satterthwaite	Unequal	304	0.03	0.9755

Referring to table 2 from Appendix B, we can say that for blend B2 emission content of O_2 is more in case of emission of RBD than that of PBSY. However, contents of other gases like CO, NO in emission are more in case of emissions of PBSY than that of RBD.

The comparative emission results of PBSY and RBD for 20 HP and 60 HP are summarized in the table below:

Oils compared	**Blend**	**Gases in Emission**	**20 HP**	**60 HP**
PBSY Vs RBD	B2	O_2	more effect on PBSY	more effect on RBD
		CO	more effect on RBD	more effect on PBSY
		NO	more effect on RBD	more effect on PBSY
		NO_2	more effect on RBD	no difference in results
		NO_X	more effect on RBD	no difference in results
		SO_2	NA	NA
		CO_2	more effect on RBD	no difference in results

2.3 PBSY Vs RBD – Blend B5 (20 HP / 60 HP)

At B5 (for 20 HP)

Using table 2.3.1 below, the probability values of all gases are less than 0.05 (Please refer the circles in green color.) hence we check for unequal variances in two sample t test.

Table 2.3.1 Equality of variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	203	152	8.01	<.0001
CO	Folded F	203	152	19.48	<.0001
NO	Folded F	203	152	14.03	<.0001
NO2	Folded F	203	152	4.67	<.0001
NOx	Folded F	203	152	14.30	<.0001
SO2	Folded F	203	152	.	.
CO2	Folded F	203	152	3.43	<.0001

From the table 2.3.2 below titled two sample t-tests we can say that all the gases have significant impact on PBSY and RBD and hence we check for the table of statistics. (Refer Table 2 from Appendix A)

Table 2.3.2 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	355	-8.11	<.0001
O2	Satterthwaite	Unequal	266	-9.07	<.0001
CO	Pooled	Equal	355	-1.91	0.0564
CO	Satterthwaite	Unequal	230	-2.18	0.0303
NO	Pooled	Equal	355	-16.98	<.0001
NO	Satterthwaite	Unequal	241	-19.23	<.0001
NO2	Pooled	Equal	355	-12.07	<.0001
NO2	Satterthwaite	Unequal	302	-13.25	<.0001
NOx	Pooled	Equal	355	-17.08	<.0001
NOx	Satterthwaite	Unequal	240	-19.35	<.0001
SO2	Pooled	Equal	355	.	.
SO2	Satterthwaite	Unequal	355	.	.
CO2	Pooled	Equal	355	5.57	<.0001
CO2	Satterthwaite	Unequal	326	6.03	<.0001

Referring to table 2 from Appendix A, we can say that for blend B5 emission content of O_2 is more in case of emission of PBSY than that of RBD. However, contents of other gases like CO, NO, NO_2, NO_x, CO_2 in emission are more in case of emissions of RBD than that of PBSY.

At B5 (for 60 HP)

Using table 2.3.3 below, the probability values of all gases except NO_2 are less than 0.05 (Please refer the circles in green color.) so we check for unequal variances in two sample t test. For NO_2, we check for equal variances.

Table 2.3.3 Equality of variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	152	152	4.19	<.0001
CO	Folded F	152	152	67.41	<.0001
NO	Folded F	152	152	7.96	<.0001
NO2	Folded F	152	152	1.25	0.1771
NOx	Folded F	152	152	7.17	<.0001
SO2	Folded F	152	152	.	.
CO2	Folded F	152	152	4.02	<.0001

From the table 2.3.4 below titled two sample t-tests we can say that all the gases except CO have significant impact on PBSY and RBD, therefore, we check for the table of statistics. (Refer Table 3 from Appendix B)

Table 2.3.4 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	304	5.84	<.0001
O2	Satterthwaite	Unequal	221	5.84	<.0001
CO	Pooled	Equal	304	-1.71	0.0884
CO	Satterthwaite	Unequal	157	-1.71	0.0894
NO	Pooled	Equal	304	-2.47	0.0142
NO	Satterthwaite	Unequal	190	-2.47	0.0145
NO2	Pooled	Equal	304	-11.52	<.0001
NO2	Satterthwaite	Unequal	300	-11.52	<.0001
NOx	Pooled	Equal	304	-2.95	0.0034
NOx	Satterthwaite	Unequal	194	-2.95	0.0036
SO2	Pooled	Equal	304	.	.
SO2	Satterthwaite	Unequal	304	.	.
CO2	Pooled	Equal	304	-5.68	<.0001
CO2	Satterthwaite	Unequal	223	-5.68	<.0001

Referring to table 3 from Appendix B, we conclude that for blend B5 emission content of O_2 is more in case of emission of RBD than that of PBSY. However, contents of other gases like gases NO, NO2, NOx, CO_2 in emission are more in case of emissions of PBSY than that of RBD.

The comparative emission results of PBSY and RBD for 20 HP and 60 HP are summarized in the table below:

Oils compared	**Blend**	**Gases in Emission**	**20 HP**	**60 HP**
PBSY Vs RBD	B5	O_2	more effect on PBSY	more effect on RBD
		CO	more effect on RBD	no difference in results
		NO	more effect on RBD	more effect on PBSY
		NO_2	more effect on RBD	more effect on PBSY
		NO_X	more effect on RBD	more effect on PBSY
		SO_2	NA	NA
		CO_2	more effect on RBD	more effect on PBSY

2.4 PBSY Vs RBD – Blend B10 (20 HP / 60 HP)

At B10 (for 20 HP)

Using table 2.4.1 below, the probability values of CO, NO_2 are greater than 0.05 (Please refer circles marked in red color.) so we check for the equal variances in two sample t-test. As the probability values for O_2, NO, NO_x, CO_2 (Please refer the circles in green color) are less than 0.05 we check for unequal variances in two sample t-test.

Table 2.4.1 Equality of variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	152	152	4.30	<.0001
CO	Folded F	152	152	1.35	0.0683
NO	Folded F	152	152	2.47	<.0001
NO2	Folded F	152	152	1.11	0.5152
NOx	Folded F	152	152	1.95	<.0001
SO2	Folded F	152	152	.	.
CO2	Folded F	152	152	2.91	<.0001

From the table 2.4.2 two sample t test we conclude that all the gases have significant effect on PBSY and RBD and we check the table for statistical differences. (Refer table 3 from Appendix A.)

Table 2.4.2 Two sample t-test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	304	-3.70	0.0003
O2	Satterthwaite	Unequal	219	-3.70	0.0003
CO	Pooled	Equal	304	4.77	<.0001
CO	Satterthwaite	Unequal	298	4.77	<.0001
NO	Pooled	Equal	304	9.49	<.0001
NO	Satterthwaite	Unequal	258	9.49	<.0001
NO2	Pooled	Equal	304	4.96	<.0001
NO2	Satterthwaite	Unequal	303	4.96	<.0001
NOx	Pooled	Equal	304	8.03	<.0001
NOx	Satterthwaite	Unequal	275	8.03	<.0001
SO2	Pooled	Equal	304	.	.
SO2	Satterthwaite	Unequal	304	.	.
CO2	Pooled	Equal	304	2.66	0.0083
CO2	Satterthwaite	Unequal	245	2.66	0.0084

Referring to table 3 from appendix A, we conclude that for blend B10, content of O_2 is more in case of emissions when RBD was used than that of when PBSY was used. Contents of other gases like CO, NO, NO_2, NO_x, CO_2 are more in case of emissions when PBSY was used than that of when RBD was used.

At B10 (for 60 HP)

Using table 2.4.3 below for equality of variance the probability values of CO is greater than 0.05 (Please refer circles marked in red color.) therefore we check for the equal variances in t-test. As the probability values for O_2, NO, NO_2, NO_x, CO_2 (Please refer the circles in green color) are less than 0.05 we check for unequal variances in t-test.

Table 2.4.3 Equality of variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	152	152	3.91	<.0001
CO	Folded F	152	152	1.17	0.3235
NO	Folded F	152	152	1.51	0.0119
NO2	Folded F	152	152	2.86	<.0001
NOx	Folded F	152	152	1.80	0.0003
SO2	Folded F	152	152	.	.
CO2	Folded F	152	152	3.09	<.0001

From the table 2.4.4 of two sample t test we can conclude that all the gases have significant effect on PBSY and RBD, therefore, we check for the table of means.

Table 2.4.4 Two sample t-test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	304	-4.05	<.0001
O2	Satterthwaite	Unequal	225	-4.05	<.0001
CO	Pooled	Equal	304	7.99	<.0001
CO	Satterthwaite	Unequal	302	7.99	<.0001
NO	Pooled	Equal	304	5.71	<.0001
NO	Satterthwaite	Unequal	292	5.71	<.0001
NO2	Pooled	Equal	304	6.64	<.0001
NO2	Satterthwaite	Unequal	247	6.64	<.0001
NOx	Pooled	Equal	304	6.16	<.0001
NOx	Satterthwaite	Unequal	281	6.16	<.0001
SO2	Pooled	Equal	304	.	.
SO2	Satterthwaite	Unequal	304	.	.
CO2	Pooled	Equal	304	2.84	0.0048
CO2	Satterthwaite	Unequal	241	2.84	0.0049

Referring to table 4 from appendix B, we conclude that for blend B10, content of O_2 is more in case of emissions when RBD is used than that of when PBSY is used. Contents of other gases like CO, NO, NO_2, NO_x, CO_2 are more in case of emissions when PBSY is used than that of when RBD is used.

The comparative emission results of PBSY and RBD at blend B10 can be summarized in the table below as:

Oils compared	Blend	Gases in Emission	20 HP	60 HP
PBSY Vs RBD	B10	O_2	more effect on RBD	more effect on RBD
		CO	more effect on PBSY	more effect on PBSY
		NO	more effect on PBSY	more effect on PBSY
		NO_2	more effect on PBSY	more effect on PBSY
		NO_X	more effect on PBSY	more effect on PBSY
		SO_2	NA	NA
		CO_2	more effect on PBSY	more effect on PBSY

2.5 PBSY Vs RBD – Blend B20 (20 HP / 60 HP)

At B20 (for 20 HP)

Using table 2.5.1 below, the probability values of CO, NO_2 are greater than 0.05 (Please refer circles marked in red color.) so we have to check for the equal variances in two sample t-test. As the probability values for O_2, NO, NO_x, CO_2 (Please refer the circles in green color) are less than 0.05 we check for unequal variances in two sample t test.

Table 2.5.1 Equality of Variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	152	152	6.08	<.0001
CO	Folded F	152	152	1.18	0.3046
NO	Folded F	152	152	4.82	<.0001
NO2	Folded F	152	152	1.18	0.3069
NOx	Folded F	152	152	2.80	<.0001
SO2	Folded F	152	152	.	.
CO2	Folded F	152	152	4.01	<.0001

From the table 2.5.2 two sample t test we conclude that all the gases have significant effect on PBSY and RBD so we check for the table for statistical differences. (Refer table 4 from Appendix A.)

Table 2.5.2 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	304	-9.62	<.0001
O2	Satterthwaite	Unequal	201	-9.62	<.0001
CO	Pooled	Equal	304	-5.81	<.0001
CO	Satterthwaite	Unequal	302	-5.81	<.0001
NO	Pooled	Equal	304	-4.81	<.0001
NO	Satterthwaite	Unequal	212	-4.81	<.0001
NO2	Pooled	Equal	304	-11.24	<.0001
NO2	Satterthwaite	Unequal	302	-11.24	<.0001
NOx	Pooled	Equal	304	-6.84	<.0001
NOx	Satterthwaite	Unequal	248	-6.84	<.0001
SO2	Pooled	Equal	304	.	.
SO2	Satterthwaite	Unequal	304	.	.
CO2	Pooled	Equal	304	7.78	<.0001
CO2	Satterthwaite	Unequal	223	7.78	<.0001

Referring to table 4 from appendix A, we conclude that for blend B20, content of O_2 is more in case of emissions when PBSY is used than that of when RBD is used. Contents of other gases like CO, NO, NO_2, NO_x, CO_2 are more in case of emissions when PBSY is used than that of when RBD is used.

At B20 (for 60 HP)

Using table 2.5.3 below, the probability values of all the gases are less than 0.05 (Please refer circles marked in green color.) so we have to check for unequal variances in two sample t-test.

Table 2.5.3 Equality of Variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	182	152	2.29	<.0001
CO	Folded F	182	152	8.24	<.0001
NO	Folded F	152	182	2.99	<.0001
NO2	Folded F	152	182	1.67	0.0009
NOx	Folded F	152	182	3.02	<.0001
SO2	Folded F	182	152	Infty	<.0001
CO2	Folded F	182	152	2.44	<.0001

From the table 2.5.4 two sample t test we conclude that all the gases have significant effect on PBSY and RBD and we check the table for statistical differences. (Refer table 5 from Appendix B.)

Table 2.5.4 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	334	-10.19	<.0001
O2	Satterthwaite	Unequal	318	-10.56	<.0001
CO	Pooled	Equal	334	6.55	<.0001
CO	Satterthwaite	Unequal	233	7.03	<.0001
NO	Pooled	Equal	334	10.47	<.0001
NO	Satterthwaite	Unequal	234	10.01	<.0001
NO2	Pooled	Equal	334	4.19	<.0001
NO2	Satterthwaite	Unequal	283	4.09	<.0001
NOx	Pooled	Equal	334	10.15	<.0001
NOx	Satterthwaite	Unequal	233	9.70	<.0001
SO2	Pooled	Equal	334	-2.02	0.0446
SO2	Satterthwaite	Unequal	182	-2.21	0.0287
CO2	Pooled	Equal	334	9.89	<.0001
CO2	Satterthwaite	Unequal	314	10.27	<.0001

Referring to table 5 from appendix B, we conclude that for blend B20, content of O_2 is more in case of emissions when RBD is used than that of when PBSY is used. Contents of other gases like CO, NO, NO_2, NO_x, CO_2 are more in case of emissions when PBSY is used than that of when RBD is used.

The comparative emission results of PBSY and RBD at blend B20 can be summarized in the table below as:

Oils compared	**Blend**	**Gases in Emission**	**20 HP**	**60 HP**
PBSY Vs RBD	B20	O_2	more effect on PBSY	more effect on RBD
		CO	more effect on RBD	more effect on PBSY
		NO	more effect on RBD	more effect on PBSY
		NO_2	more effect on RBD	more effect on PBSY
		NO_X	more effect on RBD	more effect on PBSY
		SO_2	NA	NA
		CO_2	more effect on RBD	more effect on PBSY

2.6 RBD Vs Diesel (20 HP / 60 HP)

For 20 HP

Using table 2.6.1 below, the probability values of NO2 is greater than 0.05 (Please refer circles marked in red color.) therefore we check for the equal variances in two sample t-test. As the probability values for O_2, SO_2, NO_2, NOx, CO_2 (Please refer the circles in green color) are less than 0.05 we check for unequal variances in two sample t test.

Table 2.6.1 Equality of Variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	560	152	1.76	<.0001
CO	Folded F	560	152	3.06	<.0001
NO	Folded F	560	152	2.40	<.0001
NO2	Folded F	152	560	1.07	0.6068
NOx	Folded F	560	152	2.32	<.0001
SO2	Folded F	152	560	.	.
CO2	Folded F	560	152	2.64	<.0001

From the table 2.6.2 two sample t test we conclude that all the gases other than NO2, SO2 have significant difference in effect on RBD and Diesel hence, therefore, check the table of statistical differences. (Refer table 5 from Appendix A)

Table 2.6.2 Two sample t-test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	712	-9.04	<.0001
O2	Satterthwaite	Unequal	314	-10.60	<.0001
CO	Pooled	Equal	712	7.80	<.0001
CO	Satterthwaite	Unequal	430	10.52	<.0001
NO	Pooled	Equal	712	3.47	0.0006
NO	Satterthwaite	Unequal	372	4.41	<.0001
NO2	Pooled	Equal	712	1.63	0.1036
NO2	Satterthwaite	Unequal	236	1.60	0.1108
NOx	Pooled	Equal	712	3.23	0.0013
NOx	Satterthwaite	Unequal	366	4.07	<.0001
SO2	Pooled	Equal	712	.	.
SO2	Satterthwaite	Unequal	712	.	.
CO2	Pooled	Equal	712	7.35	<.0001
CO2	Satterthwaite	Unequal	394	9.57	<.0001

Referring to table 5 from appendix A, we conclude that, contents of O_2, CO, NO in case of emissions of Diesel are more than that in case of RBD. Whereas content of gases NOx and CO2 are more in case of RBD than that of Diesel.

For 60 HP

Using table 2.6.3 below, the probability values of NO is greater than 0.05 (Please refer circles marked in red color.) so we have to check for the equal variances in two sample t-test. As the probability values for O_2, SO_2, NO_2, NOx, CO_2 (Please refer the circles in green color) are less than 0.05 we check for unequal variances in two sample t test.

Table 2.6.3 Equality of variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	641	152	3.10	<.0001
CO	Folded F	641	152	2.93	<.0001
NO	Folded F	641	152	1.06	0.6841
NO2	Folded F	641	152	688253	<.0001
NOx	Folded F	641	152	3989.12	<.0001
SO2	Folded F	641	152	Infty	<.0001
CO2	Folded F	641	152	17586.4	<.0001

From the table 2.6.4 two sample t test we conclude that all the gases other than NO_2, NO_x, SO_2, and CO_2 have significant difference in effect on RBD and Diesel hence we check the table of statistical differences. (Refer table 6 from Appendix B).

Table 2.6.4 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	793	-6.01	<.0001
O2	Satterthwaite	Unequal	407	-8.33	<.0001
CO	Pooled	Equal	793	10.60	<.0001
CO	Satterthwaite	Unequal	393	14.49	<.0001
NO	Pooled	Equal	793	6.40	<.0001
NO	Satterthwaite	Unequal	235	6.51	<.0001
NO2	Pooled	Equal	793	-0.48	0.6293
NO2	Satterthwaite	Unequal	641	-0.99	0.3228
NOx	Pooled	Equal	793	-0.38	0.7061
NOx	Satterthwaite	Unequal	642	-0.77	0.4399
SO2	Pooled	Equal	793	-0.71	0.4754
SO2	Satterthwaite	Unequal	641	-1.46	0.1438
CO2	Pooled	Equal	793	-0.40	0.6895
CO2	Satterthwaite	Unequal	641	-0.82	0.4131

Referring to table 6 from appendix B, we conclude that, content of O_2 is more in case of emissions when Diesel is used than that of when RBD is used. Contents of other gases like CO, NO are more in case of emissions when RBD is used than that of when Diesel is used.

The comparative emission results of RBD and Diesel can be summarized in the table below as:

RBD Vs Diesel	NA	O_2	more effect on diesel	more effect on diesel
		CO	more effect on diesel	more effect on RBD
		NO	more effect on diesel	more effect on RBD
		NO_2	no difference in results	no difference in results
		NO_X	more effect on RBD	no difference in results
		SO_2	no difference in results	no difference in results
		CO_2	more effect on RBD	no difference in results

2.7 PBSY Vs Diesel (20 HP / 60 HP)

For 20 HP

Using table 2.7.1 below, the probability values of O_2, CO, NO is greater than 0.05 (Please refer circles marked in red color.) so we have to check for the equal variances in two sample t-test. As the probability values for SO_2, NO_2, NOx, CO_2 (Please refer the circles in green color) are less than 0.05 we check for unequal variances in two sample t test.

Table 2.7.1 Equality of variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	5	24	1.09	0.7796
CO	Folded F	24	5	1.11	1.0000
NO	Folded F	24	5	1.10	1.0000
NO2	Folded F	24	5	665.74	<.0001
NOx	Folded F	24	5	8.94	0.0228
SO2	Folded F	24	5	Infty	<.0001
CO2	Folded F	24	5	24.62	0.0021

From the table 2.7.2 two sample t test we conclude that there is no significant difference between PBSY and diesel hence we do not check for the table of statistics.

Table 2.7.2 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	29	-0.38	0.7062
O2	Satterthwaite	Unequal	7.36	-0.37	0.7217
CO	Pooled	Equal	29	0.60	0.5549
CO	Satterthwaite	Unequal	7.91	0.62	0.5539
NO	Pooled	Equal	29	0.12	0.9063
NO	Satterthwaite	Unequal	7.87	0.12	0.9057
NO2	Pooled	Equal	29	-0.47	0.6400
NO2	Satterthwaite	Unequal	24.3	-0.97	0.3395
NOx	Pooled	Equal	29	-0.36	0.7221
NOx	Satterthwaite	Unequal	25.3	-0.62	0.5406
SO2	Pooled	Equal	29	-0.48	0.6323
SO2	Satterthwaite	Unequal	24	-1.00	0.3273
CO2	Pooled	Equal	29	-0.37	0.7118
CO2	Satterthwaite	Unequal	28.8	-0.72	0.4795

For 60 HP

Using table 2.7.3 below, the probability values of O_2, CO, NO is greater than 0.05 (Please refer circles marked in red color.) hence we check for the equal variances in two sample t-test. As the probability values for SO_2, NO_2, NOx, CO_2 (Please refer the circles in green color) are less than 0.05 we check for unequal variances in two sample t test.

Table 2.7.3 Equality of variance

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
O2	Folded F	5	24	1.09	0.7796
CO	Folded F	24	5	1.11	1.0000
NO	Folded F	24	5	1.10	1.0000
NO2	Folded F	24	5	665.74	<.0001
NOx	Folded F	24	5	8.94	0.0228
SO2	Folded F	24	5	Infty	<.0001
CO2	Folded F	24	5	24.62	0.0021

From the table 2.7.4 two sample t test we conclude that there is no significant difference between PBSY and diesel hence we do not check for the table of statistics.

Table 2.7.4 Two sample t test

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
O2	Pooled	Equal	29	-0.38	0.7062
O2	Satterthwaite	Unequal	7.36	-0.37	0.7217
CO	Pooled	Equal	29	0.60	0.5549
CO	Satterthwaite	Unequal	7.91	0.62	0.5539
NO	Pooled	Equal	29	0.12	0.9063
NO	Satterthwaite	Unequal	7.87	0.12	0.9057
NO2	Pooled	Equal	29	-0.47	0.6400
NO2	Satterthwaite	Unequal	24.3	-0.97	0.3395
NOx	Pooled	Equal	29	-0.36	0.7221
NOx	Satterthwaite	Unequal	25.3	-0.62	0.5406
SO2	Pooled	Equal	29	-0.48	0.6323
SO2	Satterthwaite	Unequal	24	-1.00	0.3273
CO2	Pooled	Equal	29	-0.37	0.7118
CO2	Satterthwaite	Unequal	28.8	-0.72	0.4795

The comparative emission results of PBSY and Diesel can be summarized in the table below as:

Oils compared	Blend	Gases in Emission	20 HP	60 HP
PBSY Vs Diesel	NA	O_2	more effect on diesel	more effect on diesel
		CO	more effect on PBSY	more effect on PBSY
		NO	more effect on PBSY	no difference in results
		NO_2	more effect on diesel	no difference in results
		NO_X	more effect on diesel	no difference in results
		SO_2	more effect on diesel	no difference in results
		CO_2	more effect on diesel	no difference in results

3. Comparison to EPA Emission Standards

PBSY v/s RBD – 20 HP

CO
Blend 10

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	PBSY	153	114.92	116.69	118.47	9.9899	11.111	12.517	0.8983	98	131
CO	RBD	153	109.51	111.04	112.57	8.6122	9.5785	10.791	0.7744	98	125
CO	Diff (1-2)		3.3198	5.6536	7.9874	9.61	10.373	11.269	1.186		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	304	-4563.1	<.0001
CO	Satterthwaite	Unequal	298	-4563.1	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	152	152	1.35	0.0683

1. From equality of variance table, as the P-value > 0.05, value for equal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for PBSY and RBD for 20 HP blend B10 are within emission standard.

Blend B2

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	PBSY	153	118.19	120.71	123.22	14.17	15.76	17.756	1.2742	98	142
CO	RBD	102	125.76	128.66	131.55	12.969	14.753	17.111	1.4608	97	146
CO	Diff (1-2)		-11.82	-7.951	-4.083	14.136	15.366	16.833	1.9642		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	253	-2762.1	<.0001
CO	Satterthwaite	Unequal	226	-2798.9	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	152	101	1.14	0.4774

1. From equality of variance table, as the P-value > 0.05, value for equal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for PBSY and RBD for 20 HP blend B2 are within emission standard.

Blend B20

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	PBSY	153	109.87	111.01	112.15	6.4118	7.1313	8.0341	0.5765	98	120
CO	RBD	153	114.51	115.56	116.61	5.8984	6.5603	7.3908	0.5304	103	122
CO	Diff (1-2)		-6.091	-4.549	-3.007	6.3477	6.8517	7.4434	0.7834		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	304	-6921.2	<.0001
CO	Satterthwaite	Unequal	302	-6921.2	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	152	152	1.18	0.3046

1. From equality of variance table, as the P-value > 0.05, value for equal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for PBSY and RBD for 20 HP blend B20 are within emission standard.

Blend B5

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	PBSY	204	114.56	116.25	117.93	11.121	12.201	13.515	0.8542	99	136
CO	RBD	153	117.73	118.17	118.61	2.4855	2.7644	3.1144	0.2235	112	124
CO	Diff (1-2)		-3.902	-1.925	0.0527	8.7584	9.402	10.149	1.0055		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	355	-5389.5	<.0001
CO	Satterthwaite	Unequal	230	-6137.4	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	203	152	19.48	<.0001

1. From equality of variance table, as the P-value > 0.05, value for equal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for PBSY and RBD for 20 HP blend B5 are within emission standard.

PBSY v/s RBD – 20 HP
NOx

Blend B10

Statistics

Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	PBSY	153	132.33	133.91	135.49	8.8848	9.8818	11.133	0.7989	119	145
NOx	RBD	153	120.68	122.88	125.09	12.411	13.804	15.551	1.116	103	144
NOx	Diff (1-2)		8.3255	11.026	13.727	11.121	12.004	13.04	1.3724		

T-Tests

Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	304	-22.96	<.0001
NOx	Satterthwaite	Unequal	275	-22.96	<.0001

Equality of Variances

Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	152	152	1.95	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for PBSY and RBD for 20 HP blend B10 are not within emission standard.

Blend B2

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	PBSY	153	130.08	132.1	134.13	11.381	12.658	14.26	1.0233	112	145
NOx	RBD	102	140.23	141.36	142.49	5.0639	5.7606	6.6812	0.5704	130	150
NOx	Diff (1-2)		-11.89	-9.258	-6.624	9.6269	10.465	11.463	1.3377		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	253	-38.72	<.0001
NOx	Satterthwaite	Unequal	228	-44.21	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	152	101	4.83	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for PBSY and RBD for 20 HP blend B2 are not within emission standard.

Blend B20

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	PBSY	153	129.78	130.99	132.2	6.8092	7.5733	8.5321	0.6123	121	144
NOx	RBD	153	137.12	139.14	141.17	11.389	12.667	14.271	1.0241	120	153
NOx	Diff (1-2)		-10.5	-8.157	-5.809	9.668	10.436	11.337	1.1931		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	304	-42.49	<.0001
NOx	Satterthwaite	Unequal	248	-42.49	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	152	152	2.80	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for PBSY and RBD for 20 HP blend B20 are not within emission standard.

Blend B5

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	PBSY	204	125.61	127.43	129.24	11.962	13.124	14.538	0.9189	117	153
NOx	RBD	153	145.47	146.02	146.57	3.1205	3.4707	3.9101	0.2806	139	152
NOx	Diff (1-2)		-20.73	-18.59	-16.45	9.4838	10.181	10.989	1.0888		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	355	-56.15	<.0001
NOx	Satterthwaite	Unequal	240	-63.63	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	203	152	14.30	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for PBSY and RBD for 20 HP blend B20 are not within emission standard.

PBSY v/s No Oil
CO

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	NO-OIL	153	123.45	124.42	125.4	5.4697	6.0835	6.8537	0.4918	115	138
CO	PBSY	663	115.23	116.17	117.12	11.763	12.396	13.102	0.4814	98	142
CO	Diff (1-2)		6.2326	8.2544	10.276	10.952	11.484	12.071	1.03		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	814	-5251.5	<.0001
CO	Satterthwaite	Unequal	481	-7859.4	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	662	152	4.15	<.0001

1. From equality of variance table, as the P-value > 0.05, value for equal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for No oil and PBSY for 20 HP blend B2 are within emission standard.

NOx

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	NO-OIL	153	139.32	140.75	142.18	8.0421	8.9445	10.077	0.7231	127	154
NOx	PBSY	663	129.95	130.82	131.7	10.875	11.46	12.113	0.4451	112	153
NOx	Diff (1-2)		7.9856	9.9281	11.871	10.523	11.034	11.597	0.9896		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	814	-32.95	<.0001
NOx	Satterthwaite	Unequal	280	-38.41	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	662	152	1.64	0.0002

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for No oil and PBSY for 20 HP blend B2 are not within emission standard.

RBD v/s No Oil
CO

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	NO-OIL	153	123.45	124.42	125.4	5.4697	6.0835	6.8537	0.4918	115	138
CO	RBD	561	116.54	117.42	118.3	10.048	10.636	11.298	0.4491	97	146
CO	Diff (1-2)		5.2417	7.0042	8.7667	9.3572	9.8429	10.382	0.8977		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	712	-6026.7	<.0001
CO	Satterthwaite	Unequal	430	-8123.7	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	560	152	3.06	<.0001

1. From equality of variance table, as the P-value > 0.05, value for equal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for No oil and RBD for 20 HP blend B2 are within emission standard.

NOx

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	NO-OIL	153	139.32	140.75	142.18	8.0421	8.9445	10.077	0.7231	127	154
NOx	RBD	561	135.86	136.99	138.12	12.882	13.635	14.484	0.5757	103	153
NOx	Diff (1-2)		1.4758	3.7641	6.0525	12.149	12.779	13.48	1.1656		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	712	-33.27	<.0001
NOx	Satterthwaite	Unequal	366	-41.95	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	560	152	2.32	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for No oil and RBD for CO are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for PBSY and RBD for 20 HP blend B2 are not within emission standard.

PBSY v/s RBD - 60 HP

CO

Blend B10

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	PBSY	153	74.117	74.961	75.804	4.7474	5.2802	5.9486	0.4269	66	84
CO	RBD	153	69.542	70.32	71.099	4.3813	4.8729	5.4898	0.394	63	81
CO	Diff (1-2)		3.4975	4.6405	5.7836	4.7069	5.0806	5.5193	0.5809		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	304	-9318.1	<.0001
CO	Satterthwaite	Unequal	302	-9318.1	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	152	152	1.17	0.3235

1. From equality of variance table, as the P-value > 0.05, value for equal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for PBSY and RBD for 60 HP blend B10 are within emission standard.

Blend B2

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	PBSY	153	79.386	81.536	83.686	12.104	13.462	15.167	1.0884	64	200
CO	RBD	153	74.568	76	77.432	8.063	8.9678	10.103	0.725	66	156
CO	Diff (1-2)		2.9626	5.5359	8.1093	10.597	11.438	12.426	1.3077		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	304	-4138.3	<.0001
CO	Satterthwaite	Unequal	265	-4138.3	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	152	152	2.25	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for PBSY and RBD for 60 HP blend B2 are within emission standard.

Blend B20

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	PBSY	153	74.215	75.124	76.033	5.1167	5.6909	6.4113	0.4601	62	84
CO	RBD	183	63.661	66.044	68.426	14.816	16.335	18.205	1.2075	0	75
CO	Diff (1-2)		6.3535	9.0805	11.807	11.764	12.655	13.693	1.3863		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	334	-3901.3	<.0001
CO	Satterthwaite	Unequal	233	-4185.3	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	182	152	8.24	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for PBSY and RBD for 60 HP blend B20 are within emission standard.

Blend B5

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	PBSY	153	72.917	77.686	82.455	26.846	29.859	33.639	2.4139	18	121
CO	RBD	153	81.262	81.843	82.424	3.2697	3.6367	4.097	0.294	74	92
CO	Diff (1-2)		-8.942	-4.157	0.6284	19.705	21.269	23.106	2.4318		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	304	-2229.4	<.0001
CO	Satterthwaite	Unequal	157	-2229.4	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	152	152	67.41	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for CO are < 5417.36.

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for PBSY and RBD for 60 HP blend B5 are within emission standard.

PBSY v/s RBD - 60 HP
NOx

Blend B10

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	PBSY	153	300.44	305.73	311.01	29.737	33.074	37.261	2.6738	262	351
NOx	RBD	153	281.25	285.19	289.13	22.167	24.654	27.775	1.9932	256	342
NOx	Diff (1-2)		13.973	20.536	27.099	27.023	29.169	31.688	3.335		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	304	-6.60	<.0001
NOx	Satterthwaite	Unequal	281	-6.60	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	152	152	1.80	0.0003

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for NOx are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for PBSY and RBD for 60 HP blend B10 are not within emission standard.

Blend B2

Statistics

Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	PBSY	153	-94.78	747.41	1589.6	4740.8	5272.8	5940.3	426.28	225	65535
NOx	RBD	153	-141.4	701.32	1544	4743.7	5276	5943.9	426.54	249	65535
NOx	Diff (1-2)		-1141	46.092	1232.7	4886.4	5274.4	5729.8	603.03		

T-Tests

Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	304	0.01	0.9953
NOx	Satterthwaite	Unequal	304	0.01	0.9953

Equality of Variances

Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	152	152	1.00	0.9940

1. From equality of variance table, as the P-value > 0.05, value for equal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for NOx are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for PBSY and RBD for 60 HP blend B2 are not within emission standard.

Blend B20

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	PBSY	153	313.98	324.23	334.48	57.712	64.188	72.314	5.1893	216	415
NOx	RBD	183	261.95	267.34	272.73	33.518	36.956	41.186	2.7319	9	290
NOx	Diff (1-2)		45.856	56.884	67.913	47.574	51.178	55.378	5.6064		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	334	2.56	0.0110
NOx	Satterthwaite	Unequal	233	2.45	0.0152

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	152	182	3.02	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for NOx are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for PBSY and RBD for 60 HP blend B20 are not within emission standard.

Blend B5

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	PBSY	153	295.97	311.14	326.31	85.395	94.978	107	7.6785	221	488
NOx	RBD	153	329.65	335.32	340.99	31.896	35.475	39.966	2.868	270	414
NOx	Diff (1-2)		-40.31	-24.18	-8.047	66.417	71.691	77.882	8.1966		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	304	-8.14	<.0001
NOx	Satterthwaite	Unequal	194	-8.14	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	152	152	7.17	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for PBSY and RBD for NOx are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.00005 (< 0.05), hence NOx emissions for PBSY and RBD for 60 HP blend B6 are not within emission standard.

PBSY v/s No Oil
CO

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	NO-OIL	153	82.642	83.745	84.848	6.2083	6.9049	7.7791	0.5582	71	94
CO	PBSY	612	75.977	77.327	78.676	16.097	16.999	18.009	0.6871	18	200
CO	Diff (1-2)		3.6643	6.4183	9.1723	14.78	15.521	16.341	1.4029		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	763	-3857.0	<.0001
CO	Satterthwaite	Unequal	612	-6111.9	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	611	152	6.06	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for No oil and PBSY for CO are < 5417.36

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for No oil and PBSY for 60 HP are within emission standard.

NOx

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	NO-OIL	153	306.11	312.63	319.14	36.661	40.775	45.937	3.2965	261	434
NOx	PBSY	612	212.77	422.13	631.49	2497.4	2637.3	2794	106.61	216	65535
NOx	Diff (1-2)		-528.3	-109.5	309.27	2247.4	2360.1	2484.8	213.32		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	763	-0.71	0.4762
NOx	Satterthwaite	Unequal	612	-1.43	0.1545

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	611	152	4183.36	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for No oil and PBSY for NOx are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.07725 (> 0.05), hence NOx emissions for No oil and PBSY for 60 HP blend are within emission standard.

RBD v/s No Oil
CO

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
CO	NO-OIL	153	82.642	83.745	84.848	6.2083	6.9049	7.7791	0.5582	71	94
CO	RBD	642	72.284	73.201	74.118	11.215	11.828	12.513	0.4668	0	156
CO	Diff (1-2)		8.5918	10.544	12.497	10.537	11.056	11.628	0.9946		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
CO	Pooled	Equal	793	-5436.1	<.0001
CO	Satterthwaite	Unequal	393	-7430.0	<.0001

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
CO	Folded F	641	152	2.93	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for No oil and PBSY for CO are < 5417.36

3. As the hypothesis is one sided P value is (1- (P/2)) = 0.99995 (> 0.05), hence CO emissions for No oil and RBD for 60 HP are within emission standard.

NOx

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
NOx	NO-OIL	153	306.11	312.63	319.14	36.661	40.775	45.937	3.2965	261	434
NOx	RBD	642	191.63	391.22	590.81	2441.8	2575.3	2724.5	101.64	9	65535
NOx	Diff (1-2)		-487.5	-78.59	330.31	2206.9	2315.5	2435.3	208.31		

T-Tests					
Variable	Method	Variances	DF	t Value	Pr > |t|
NOx	Pooled	Equal	793	-0.58	0.5611
NOx	Satterthwaite	Unequal	642	-1.19	0.2340

Equality of Variances					
Variable	Method	Num DF	Den DF	F Value	Pr > F
NOx	Folded F	641	152	3989.12	<.0001

1. From equality of variance table, as the P-value < 0.05, value for unequal variance is to be considered in t-test.

2. From the statistics we observe that the means for No oil and PBSY for NOx are > 42.5414.

3. As the hypothesis is one sided P value is (P/2) = 0.117(> 0.05), hence NOx emissions for No oil and PBSY for 60 HP blend are within emission standard.

Results and Conclusions

60 HP								
Blends	**PBSY**				**RBD**			
	CO		**NOx**		**CO**		**NOx**	
B2	79.386	< 5417.36 hence within emission limits	747.41	> 42.5414 hence not within emission limits.	74.568	< 5417.36 hence within emission limits, and RBD is better than PBSY.	701.32	> 42.5414 hence not within emission limits, and RBD is better than PBSY.
B5	77.686	< 5417.36 hence within emission limits	311.14	> 42.5414 hence not within emission limits.	81.843	< 5417.36 hence within emission limits	335.32	> 42.5414 hence not within emission limits.
B10	74.961	< 5417.36 hence within emission limits	305.73	> 42.5414 hence not within emission limits.	70.32	< 5417.36 hence within emission limits, and RBD is better than PBSY.	285.19	> 42.5414 hence not within emission limits, and RBD is better than PBSY.
B20	75.124	< 5417.36 hence within emission limits	324.23	> 42.5414 hence not within emission limits.	66.044	< 5417.36 hence within emission limits, and RBD is better than PBSY.	267.34	> 42.5414 hence not within emission limits, and RBD is better than PBSY.
No blends	**CO**				**NOx**			
	No oil		**PBSY**		**No oil**		**PBSY**	
	83.745	< 5417.36 hence within emission limits	77.327	< 5417.36 hence within emission limits	312.63	> 42.5414 but the P-value is > 0.05 hence within emission limits	422.13	> 42.5414 but the P-value is > 0.05 hence within emission limits
	No oil		**RBD**		**No oil**		**RBD**	
	83.745	< 5417.36 hence within emission limits	73.201	< 5417.36 hence within emission limits, and RBD is better than PBSY.	312.63	> 42.5414 but the P-value is > 0.05 hence within emission limits	391.22	> 42.5414 but the P-value is > 0.05 hence within emission limits, and RBD is better than PBSY.

Appendix A

Table 1

PBSY Vs RBD for complete data

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
O2	**PBSY**	663	18.995	19.011	19.027	0.2027	0.2136	0.2258	0.0083	18.7	19.3
O2	**RBD**	561	19.038	19.053	19.068	0.1716	0.1816	0.1929	0.0077	18.7	19.3
O2	**Diff (1-2)**		-0.064	-0.042	-0.019	0.192	0.1996	0.2079	0.0115		
CO	**PBSY**	663	115.23	116.17	117.12	11.763	12.396	13.102	0.4814	98	142
CO	**RBD**	561	116.54	117.42	118.3	10.048	10.636	11.298	0.4491	97	146
CO	**Diff (1-2)**		-2.558	-1.25	0.0579	11.18	11.623	12.103	0.6668		
NO	**PBSY**	663	96.827	97.499	98.172	8.3696	8.8201	9.3223	0.3425	81	116
NO	**RBD**	561	100.86	101.77	102.67	10.333	10.938	11.619	0.4618	77	114
NO	**Diff (1-2)**		-5.376	-4.267	-3.159	9.4721	9.8475	10.254	0.5649		
NO2	**PBSY**	663	33.027	33.324	33.621	3.6949	3.8938	4.1156	0.1512	25	40
NO2	**RBD**	561	34.931	35.221	35.511	3.3081	3.5017	3.7195	0.1478	26	40
NO2	**Diff (1-2)**		-2.315	-1.897	-1.478	3.5775	3.7193	3.8728	0.2134		
NOx	**PBSY**	663	129.95	130.82	131.7	10.875	11.46	12.113	0.4451	112	153
NOx	**RBD**	561	135.86	136.99	138.12	12.882	13.635	14.484	0.5757	103	153
NOx	**Diff (1-2)**		-7.571	-6.164	-4.757	12.027	12.504	13.02	0.7173		
SO2	**PBSY**	663	0	0	0	.	0	.	0	0	0
SO2	**RBD**	561	0	0	0	.	0	.	0	0	0
SO2	**Diff (1-2)**		.	0	.	.	0	.	.		
CO2	**PBSY**	663	1.4298	1.4427	1.4555	0.1597	0.1683	0.1779	0.0065	1.2	1.7
CO2	**RBD**	561	1.4162	1.4287	1.4412	0.1425	0.1509	0.1603	0.0064	1.2	1.7
CO2	**Diff (1-2)**		-0.004	0.014	0.0321	0.1545	0.1606	0.1672	0.0092		

Table 2

PBSY Vs RBD at blend B5

Statistics											
Variable	**Fuel Type**	**N**	**Lower CL Mean**	**Mean**	**Upper CL Mean**	**Lower CL Std Dev**	**Std Dev**	**Upper CL Std Dev**	**Std Err**	**Minimum**	**Maximum**
O2	**PBSY**	153	19.049	19.076	19.104	0.1546	0.172	0.1937	0.0139	18.8	19.3
O2	**RBD**	102	18.721	18.731	18.742	0.0479	0.0545	0.0632	0.0054	18.7	18.9
O2	**Diff (1-2)**		0.3104	0.3451	0.3798	0.1266	0.1377	0.1508	0.0176		
CO	**PBSY**	153	118.19	120.71	123.22	14.17	15.76	17.756	1.2742	98	142
CO	**RBD**	102	125.76	128.66	131.55	12.969	14.753	17.111	1.4608	97	146
CO	**Diff (1-2)**		-11.82	-7.951	-4.083	14.136	15.366	16.833	1.9642		
NO	**PBSY**	153	96.266	98.072	99.878	10.168	11.309	12.741	0.9143	81	109
NO	**RBD**	102	104.61	105.24	105.86	2.7886	3.1722	3.6792	0.3141	97	110
NO	**Diff (1-2)**		-9.427	-7.163	-4.9	8.2721	8.992	9.8502	1.1494		
NO2	**PBSY**	153	33.508	34.033	34.557	2.9541	3.2856	3.7015	0.2656	29	39
NO2	**RBD**	102	35.521	36.127	36.734	2.7149	3.0884	3.5819	0.3058	29	40
NO2	**Diff (1-2)**		-2.902	-2.095	-1.287	2.9515	3.2083	3.5145	0.4101		
NOx	**PBSY**	153	130.08	132.1	134.13	11.381	12.658	14.26	1.0233	112	145
NOx	**RBD**	102	140.23	141.36	142.49	5.0639	5.7606	6.6812	0.5704	130	150
NOx	**Diff (1-2)**		-11.89	-9.258	-6.624	9.6269	10.465	11.463	1.3377		
SO2	**PBSY**	153	0	0	0	.	0	.	0	0	0
SO2	**RBD**	102	0	0	0	.	0	.	0	0	0
SO2	**Diff (1-2)**		.	0	.	.	0	.	.		
CO2	**PBSY**	153	1.3692	1.3902	1.4111	0.1179	0.1312	0.1478	0.0106	1.2	1.6
CO2	**RBD**	102	1.6579	1.6686	1.6793	0.0479	0.0545	0.0632	0.0054	1.5	1.7
CO2	**Diff (1-2)**		-0.305	-0.278	-0.251	0.0987	0.1073	0.1176	0.0137		

Table 3

PBSY Vs RBD at blend B10

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
O2	PBSY	3	18.273	19.065	19.857	0.166	0.3187	2.0032	0.184	18.702	19.3
O2	RBD	3	18.779	19.152	19.524	0.0781	0.15	0.9429	0.0866	19	19.3
O2	Diff (1-2)		-0.652	-0.087	0.4778	0.1492	0.2491	0.7158	0.2034		
CO	PBSY	3	83.495	116.69	149.89	6.958	13.364	83.988	7.7156	102.49	129.02
CO	RBD	3	82.257	111.04	139.82	6.0326	11.586	72.818	6.6894	102.63	124.25
CO	Diff (1-2)		-22.7	5.6536	34.006	7.4932	12.507	35.939	10.212		
NO	PBSY	3	80.492	98.255	116.02	3.7231	7.1507	44.94	4.1285	90.412	104.41
NO	RBD	3	61.547	89.686	117.83	5.8977	11.327	71.19	6.5399	79.529	101.9
NO	Diff (1-2)		-12.9	8.5686	30.042	5.6751	9.4722	27.219	7.734		
NO2	PBSY	3	23.066	35.654	48.241	2.6382	5.067	31.845	2.9255	29.882	39.373
NO2	RBD	3	19.899	33.196	46.494	2.7871	5.3529	33.642	3.0905	27.843	38.549
NO2	Diff (1-2)		-9.358	2.4575	14.273	3.1227	5.212	14.977	4.2555		
NOx	PBSY	3	104.41	133.91	163.4	6.182	11.873	74.622	6.8551	120.29	142.12
NOx	RBD	3	81.559	122.88	164.21	8.6612	16.635	104.55	9.6042	107.37	140.45
NOx	Diff (1-2)		-21.74	11.026	43.788	8.6585	14.452	41.528	11.8		
SO2	PBSY	3	0	0	0	.	0	.	0	0	0
SO2	RBD	3	0	0	0	.	0	.	0	0	0
SO2	Diff (1-2)		.	0	.	.	0	.	.		
CO2	PBSY	3	0.7511	1.402	2.0529	0.1364	0.262	1.6467	0.1513	1.2	1.698
CO2	RBD	3	0.9757	1.3484	1.7211	0.0781	0.15	0.9429	0.0866	1.2	1.5
CO2	Diff (1-2)		-0.43	0.0536	0.5376	0.1279	0.2135	0.6135	0.1743		

Table 4

PBSY Vs RBD at blend B20

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
O2	PBSY	153	19.049	19.076	19.104	0.1546	0.172	0.1937	0.0139	18.8	19.3
O2	RBD	102	18.721	18.731	18.742	0.0479	0.0545	0.0632	0.0054	18.7	18.9
O2	Diff (1-2)		0.3104	0.3451	0.3798	0.1266	0.1377	0.1508	0.0176		
CO	PBSY	153	118.19	120.71	123.22	14.17	15.76	17.756	1.2742	98	142
CO	RBD	102	125.76	128.66	131.55	12.969	14.753	17.111	1.4608	97	146
CO	Diff (1-2)		-11.82	-7.951	-4.083	14.136	15.366	16.833	1.9642		
NO	PBSY	153	96.266	98.072	99.878	10.168	11.309	12.741	0.9143	81	109
NO	RBD	102	104.61	105.24	105.86	2.7886	3.1722	3.6792	0.3141	97	110
NO	Diff (1-2)		-9.427	-7.163	-4.9	8.2721	8.992	9.8502	1.1494		
NO2	PBSY	153	33.508	34.033	34.557	2.9541	3.2856	3.7015	0.2656	29	39
NO2	RBD	102	35.521	36.127	36.734	2.7149	3.0884	3.5819	0.3058	29	40
NO2	Diff (1-2)		-2.902	-2.095	-1.287	2.9515	3.2083	3.5145	0.4101		
NOx	PBSY	153	130.08	132.1	134.13	11.381	12.658	14.26	1.0233	112	145
NOx	RBD	102	140.23	141.36	142.49	5.0639	5.7606	6.6812	0.5704	130	150
NOx	Diff (1-2)		-11.89	-9.258	-6.624	9.6269	10.465	11.463	1.3377		
SO2	PBSY	153	0	0	0	.	0	.	0	0	0
SO2	RBD	102	0	0	0	.	0	.	0	0	0
SO2	Diff (1-2)		.	0	.	.	0	.	.		
CO2	PBSY	153	1.3692	1.3902	1.4111	0.1179	0.1312	0.1478	0.0106	1.2	1.6
CO2	RBD	102	1.6579	1.6686	1.6793	0.0479	0.0545	0.0632	0.0054	1.5	1.7
CO2	Diff (1-2)		-0.305	-0.278	-0.251	0.0987	0.1073	0.1176	0.0137		

Table 5

RBD Vs Diesel

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
O2	NO-OIL	153	18.889	18.91	18.932	0.123	0.1368	0.1541	0.0111	18.7	19.1
O2	RBD	561	19.038	19.053	19.068	0.1716	0.1816	0.1929	0.0077	18.7	19.3
O2	Diff (1-2)		-0.174	-0.143	-0.112	0.1645	0.173	0.1825	0.0158		
CO	NO-OIL	153	123.45	124.42	125.4	5.4697	6.0835	6.8537	0.4918	115	138
CO	RBD	561	116.54	117.42	118.3	10.048	10.636	11.298	0.4491	97	146
CO	Diff (1-2)		5.2417	7.0042	8.7667	9.3572	9.8429	10.382	0.8977		
NO	NO-OIL	153	103.88	105.01	106.14	6.3547	7.0678	7.9626	0.5714	97	116
NO	RBD	561	100.86	101.77	102.67	10.333	10.938	11.619	0.4618	77	114
NO	Diff (1-2)		1.4072	3.24	5.0729	9.7304	10.236	10.796	0.9335		
NO2	NO-OIL	153	35.168	35.745	36.322	3.2492	3.6138	4.0713	0.2922	29	40
NO2	RBD	561	34.931	35.221	35.511	3.3081	3.5017	3.7195	0.1478	26	40
NO2	Diff (1-2)		-0.107	0.5241	1.1554	3.3519	3.5259	3.7191	0.3216		
NOx	NO-OIL	153	139.32	140.75	142.18	8.0421	8.9445	10.077	0.7231	127	154
NOx	RBD	561	135.86	136.99	138.12	12.882	13.635	14.484	0.5757	103	153
NOx	Diff (1-2)		1.4758	3.7641	6.0525	12.149	12.779	13.48	1.1656		
SO2	NO-OIL	153	0	0	0	.	0	.	0	0	0
SO2	RBD	561	0	0	0	.	0	.	0	0	0
SO2	Diff (1-2)		.	0	.	.	0	.	.		
CO2	NO-OIL	153	1.508	1.5229	1.5377	0.0835	0.0928	0.1046	0.0075	1.4	1.7
CO2	RBD	561	1.4162	1.4287	1.4412	0.1425	0.1509	0.1603	0.0064	1.2	1.7
CO2	Diff (1-2)		0.069	0.0942	0.1193	0.1336	0.1405	0.1482	0.0128		

Appendix B

Table 1

PBSY Vs RBD for complete data

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
O2	PBSY	612	17.395	17.433	17.47	0.4446	0.4695	0.4974	0.019	16.3	18.2
O2	RBD	642	17.534	17.578	17.622	0.538	0.5675	0.6003	0.0224	7.8	21
O2	Diff (1-2)		-0.204	-0.146	-0.088	0.5023	0.522	0.5433	0.0295		
CO	PBSY	612	75.977	77.327	78.676	16.097	16.999	18.009	0.6871	18	200
CO	RBD	642	72.284	73.201	74.118	11.215	11.828	12.513	0.4668	0	156
CO	Diff (1-2)		2.5096	4.1259	5.7421	14.033	14.582	15.177	0.8238		
NO	PBSY	612	292.08	297.53	302.98	64.996	68.638	72.715	2.7745	0	464
NO	RBD	642	268.56	271.58	274.61	37.038	39.064	41.326	1.5417	0	398
NO	Diff (1-2)		19.792	25.944	32.095	53.41	55.501	57.764	3.1355		
NO2	PBSY	612	-85.64	124.6	334.84	2507.9	2648.4	2805.7	107.05	10	65535
NO2	RBD	642	-80.76	119.64	320.03	2451.6	2585.8	2735.5	102.05	1	65535
NO2	Diff (1-2)		-285	4.9626	294.96	2517.9	2616.5	2723.2	147.82		
NOx	PBSY	612	212.77	422.13	631.49	2497.4	2637.3	2794	106.61	216	65535
NOx	RBD	642	191.63	391.22	590.81	2441.8	2575.3	2724.5	101.64	9	65535
NOx	Diff (1-2)		-257.9	30.906	319.71	2507.6	2605.7	2712	147.21		
SO2	PBSY	612	-0.03	0.031	0.092	0.7273	0.768	0.8137	0.031	0	19
SO2	RBD	642	-0.014	0.0421	0.0985	0.6904	0.7282	0.7703	0.0287	0	18
SO2	Diff (1-2)		-0.094	-0.011	0.0719	0.7197	0.7479	0.7784	0.0423		
CO2	PBSY	612	1.3251	3.9456	6.5661	31.259	33.01	34.971	1.3344	2.1	819.2
CO2	RBD	642	1.268	3.7662	6.2644	30.562	32.234	34.101	1.2722	0	819.2
CO2	Diff (1-2)		-3.436	0.1794	3.7943	31.387	32.615	33.945	1.8426		

Table 2

PBSY Vs RBD at blend B2

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
O2	PBSY	153	17.471	17.51	17.55	0.2224	0.2474	0.2787	0.02	17.2	17.8
O2	RBD	153	17.581	17.601	17.621	0.1125	0.1251	0.141	0.0101	17.4	17.9
O2	Diff (1-2)		-0.135	-0.091	-0.047	0.1816	0.196	0.213	0.0224		
CO	PBSY	153	74.117	74.961	75.804	4.7474	5.2802	5.9486	0.4269	66	84
CO	RBD	153	69.542	70.32	71.099	4.3813	4.8729	5.4898	0.394	63	81
CO	Diff (1-2)		3.4975	4.6405	5.7836	4.7069	5.0806	5.5193	0.5809		
NO	PBSY	153	282.02	287.01	292.01	28.116	31.271	35.23	2.5281	244	330
NO	RBD	153	264.33	268.4	272.47	22.904	25.474	28.699	2.0594	238	327
NO	Diff (1-2)		12.198	18.614	25.031	26.422	28.52	30.983	3.2608		
NO2	PBSY	153	18.22	18.712	19.205	2.7706	3.0815	3.4716	0.2491	14	26
NO2	RBD	153	16.5	16.791	17.082	1.6393	1.8233	2.0541	0.1474	12	20
NO2	Diff (1-2)		1.352	1.9216	2.4912	2.3456	2.5318	2.7504	0.2895		
NOx	PBSY	153	300.44	305.73	311.01	29.737	33.074	37.261	2.6738	262	351
NOx	RBD	153	281.25	285.19	289.13	22.167	24.654	27.775	1.9932	256	342
NOx	Diff (1-2)		13.973	20.536	27.099	27.023	29.169	31.688	3.335		
SO2	PBSY	153	0	0	0	.	0	.	0	0	0
SO2	RBD	153	0	0	0	.	0	.	0	0	0
SO2	Diff (1-2)		.	0	.	.	0	.	.		
CO2	PBSY	153	2.5192	2.5516	2.5841	0.1825	0.203	0.2287	0.0164	2.3	2.8
CO2	RBD	153	2.4796	2.498	2.5165	0.1039	0.1155	0.1302	0.0093	2.3	2.6
CO2	Diff (1-2)		0.0164	0.0536	0.0908	0.153	0.1652	0.1794	0.0189		

Table 3

PBSY Vs RBD at blend B5

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
O2	PBSY	153	17.471	17.51	17.55	0.2224	0.2474	0.2787	0.02	17.2	17.8
O2	RBD	153	17.581	17.601	17.621	0.1125	0.1251	0.141	0.0101	17.4	17.9
O2	Diff (1-2)		-0.135	-0.091	-0.047	0.1816	0.196	0.213	0.0224		
CO	PBSY	153	74.117	74.961	75.804	4.7474	5.2802	5.9486	0.4269	66	84
CO	RBD	153	69.542	70.32	71.099	4.3813	4.8729	5.4898	0.394	63	81
CO	Diff (1-2)		3.4975	4.6405	5.7836	4.7069	5.0806	5.5193	0.5809		
NO	PBSY	153	282.02	287.01	292.01	28.116	31.271	35.23	2.5281	244	330
NO	RBD	153	264.33	268.4	272.47	22.904	25.474	28.699	2.0594	238	327
NO	Diff (1-2)		12.198	18.614	25.031	26.422	28.52	30.983	3.2608		
NO2	PBSY	153	18.22	18.712	19.205	2.7706	3.0815	3.4716	0.2491	14	26
NO2	RBD	153	16.5	16.791	17.082	1.6393	1.8233	2.0541	0.1474	12	20
NO2	Diff (1-2)		1.352	1.9216	2.4912	2.3456	2.5318	2.7504	0.2895		
NOx	PBSY	153	300.44	305.73	311.01	29.737	33.074	37.261	2.6738	262	351
NOx	RBD	153	281.25	285.19	289.13	22.167	24.654	27.775	1.9932	256	342
NOx	Diff (1-2)		13.973	20.536	27.099	27.023	29.169	31.688	3.335		
SO2	PBSY	153	0	0	0	.	0	.	0	0	0
SO2	RBD	153	0	0	0	.	0	.	0	0	0
SO2	Diff (1-2)		.	0	.	.	0	.	.		
CO2	PBSY	153	2.5192	2.5516	2.5841	0.1825	0.203	0.2287	0.0164	2.3	2.8
CO2	RBD	153	2.4796	2.498	2.5165	0.1039	0.1155	0.1302	0.0093	2.3	2.6
CO2	Diff (1-2)		0.0164	0.0536	0.0908	0.153	0.1652	0.1794	0.0189		

Table 4

PBSY Vs RBD at blend B10

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
O2	PBSY	153	17.471	17.51	17.55	0.2224	0.2474	0.2787	0.02	17.2	17.8
O2	RBD	153	17.581	17.601	17.621	0.1125	0.1251	0.141	0.0101	17.4	17.9
O2	Diff (1-2)		-0.135	-0.091	-0.047	0.1816	0.196	0.213	0.0224		
CO	PBSY	153	74.117	74.961	75.804	4.7474	5.2802	5.9486	0.4269	66	84
CO	RBD	153	69.542	70.32	71.099	4.3813	4.8729	5.4898	0.394	63	81
CO	Diff (1-2)		3.4975	4.6405	5.7836	4.7069	5.0806	5.5193	0.5809		
NO	PBSY	153	282.02	287.01	292.01	28.116	31.271	35.23	2.5281	244	330
NO	RBD	153	264.33	268.4	272.47	22.904	25.474	28.699	2.0594	238	327
NO	Diff (1-2)		12.198	18.614	25.031	26.422	28.52	30.983	3.2608		
NO2	PBSY	153	18.22	18.712	19.205	2.7706	3.0815	3.4716	0.2491	14	26
NO2	RBD	153	16.5	16.791	17.082	1.6393	1.8233	2.0541	0.1474	12	20
NO2	Diff (1-2)		1.352	1.9216	2.4912	2.3456	2.5318	2.7504	0.2895		
NOx	PBSY	153	300.44	305.73	311.01	29.737	33.074	37.261	2.6738	262	351
NOx	RBD	153	281.25	285.19	289.13	22.167	24.654	27.775	1.9932	256	342
NOx	Diff (1-2)		13.973	20.536	27.099	27.023	29.169	31.688	3.335		
SO2	PBSY	153	0	0	0	.	0	.	0	0	0
SO2	RBD	153	0	0	0	.	0	.	0	0	0
SO2	Diff (1-2)		.	0	.	.	0	.	.		
CO2	PBSY	153	2.5192	2.5516	2.5841	0.1825	0.203	0.2287	0.0164	2.3	2.8
CO2	RBD	153	2.4796	2.498	2.5165	0.1039	0.1155	0.1302	0.0093	2.3	2.6
CO2	Diff (1-2)		0.0164	0.0536	0.0908	0.153	0.1652	0.1794	0.0189		

Table 5

PBSY Vs RBD at blend B20

Statistics											
Variable	**Fuel Type**	**N**	**Lower CL Mean**	**Mean**	**Upper CL Mean**	**Lower CL Std Dev**	**Std Dev**	**Upper CL Std Dev**	**Std Err**	**Minimum**	**Maximum**
O2	**PBSY**	153	17.471	17.51	17.55	0.2224	0.2474	0.2787	0.02	17.2	17.8
O2	**RBD**	153	17.581	17.601	17.621	0.1125	0.1251	0.141	0.0101	17.4	17.9
O2	**Diff (1-2)**		-0.135	-0.091	-0.047	0.1816	0.196	0.213	0.0224		
CO	**PBSY**	153	74.117	74.961	75.804	4.7474	5.2802	5.9486	0.4269	66	84
CO	**RBD**	153	69.542	70.32	71.099	4.3813	4.8729	5.4898	0.394	63	81
CO	**Diff (1-2)**		3.4975	4.6405	5.7836	4.7069	5.0806	5.5193	0.5809		
NO	**PBSY**	153	282.02	287.01	292.01	28.116	31.271	35.23	2.5281	244	330
NO	**RBD**	153	264.33	268.4	272.47	22.904	25.474	28.699	2.0594	238	327
NO	**Diff (1-2)**		12.198	18.614	25.031	26.422	28.52	30.983	3.2608		
NO2	**PBSY**	153	18.22	18.712	19.205	2.7706	3.0815	3.4716	0.2491	14	26
NO2	**RBD**	153	16.5	16.791	17.082	1.6393	1.8233	2.0541	0.1474	12	20
NO2	**Diff (1-2)**		1.352	1.9216	2.4912	2.3456	2.5318	2.7504	0.2895		
NOx	**PBSY**	153	300.44	305.73	311.01	29.737	33.074	37.261	2.6738	262	351
NOx	**RBD**	153	281.25	285.19	289.13	22.167	24.654	27.775	1.9932	256	342
NOx	**Diff (1-2)**		13.973	20.536	27.099	27.023	29.169	31.688	3.335		
SO2	**PBSY**	153	0	0	0	.	0	.	0	0	0
SO2	**RBD**	153	0	0	0	.	0	.	0	0	0
SO2	**Diff (1-2)**		.	0	.	.	0	.	.		
CO2	**PBSY**	153	2.5192	2.5516	2.5841	0.1825	0.203	0.2287	0.0164	2.3	2.8
CO2	**RBD**	153	2.4796	2.498	2.5165	0.1039	0.1155	0.1302	0.0093	2.3	2.6
CO2	**Diff (1-2)**		0.0164	0.0536	0.0908	0.153	0.1652	0.1794	0.0189		

Table 6

RBD Vs Diesel

Statistics											
Variable	Fuel Type	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err	Minimum	Maximum
O2	**NO-OIL**	153	17.241	17.292	17.344	0.29	0.3225	0.3633	0.0261	16.5	17.9
O2	**RBD**	642	17.534	17.578	17.622	0.538	0.5675	0.6003	0.0224	7.8	21
O2	**Diff (1-2)**		-0.38	-0.286	-0.193	0.5045	0.5294	0.5568	0.0476		
CO	**NO-OIL**	153	82.642	83.745	84.848	6.2083	6.9049	7.7791	0.5582	71	94
CO	**RBD**	642	72.284	73.201	74.118	11.215	11.828	12.513	0.4668	0	156
CO	**Diff (1-2)**		8.5918	10.544	12.497	10.537	11.056	11.628	0.9946		
NO	**NO-OIL**	153	287.91	293.97	300.04	34.159	37.992	42.802	3.0715	246	408
NO	**RBD**	642	268.56	271.58	274.61	37.038	39.064	41.326	1.5417	0	398
NO	**Diff (1-2)**		15.527	22.39	29.252	37.039	38.861	40.873	3.4961		
NO2	**NO-OIL**	153	18.156	18.654	19.151	2.8024	3.1168	3.5114	0.252	13	26
NO2	**RBD**	642	-80.76	119.64	320.03	2451.6	2585.8	2735.5	102.05	1	65535
NO2	**Diff (1-2)**		-511.5	-101	309.56	2215.8	2324.8	2445.1	209.15		
NOx	**NO-OIL**	153	306.11	312.63	319.14	36.661	40.775	45.937	3.2965	261	434
NOx	**RBD**	642	191.63	391.22	590.81	2441.8	2575.3	2724.5	101.64	9	65535
NOx	**Diff (1-2)**		-487.5	-78.59	330.31	2206.9	2315.5	2435.3	208.31		
SO2	**NO-OIL**	153	0	0	0	.	0	.	0	0	0
SO2	**RBD**	642	-0.014	0.0421	0.0985	0.6904	0.7282	0.7703	0.0287	0	18
SO2	**Diff (1-2)**		-0.158	-0.042	0.0736	0.624	0.6547	0.6886	0.0589		
CO2	**NO-OIL**	153	2.6854	2.7242	2.763	0.2185	0.2431	0.2738	0.0197	2.3	3.3
CO2	**RBD**	642	1.268	3.7662	6.2644	30.562	32.234	34.101	1.2722	0	819.2
CO2	**Diff (1-2)**		-6.16	-1.042	4.0759	27.622	28.981	30.481	2.6073		

Comparative emission test results of PBSY/RBD/Diesel

Oils compared	Blend	Gases in Emission	20 HP	60 HP
PBSY Vs RBD	Complete Data	O_2	no difference in results	more effect on RBD
		CO		more effect on PBSY
		NO		more effect on PBSY
		NO_2		no difference in results
		NO_X		no difference in results
		SO_2		NA
		CO_2		no difference in results
PBSY Vs RBD	B2	O_2	more effect on PBSY	more effect on RBD
		CO	more effect on RBD	more effect on PBSY
		NO	more effect on RBD	more effect on PBSY
		NO_2	more effect on RBD	no difference in results
		NO_X	more effect on RBD	no difference in results
		SO_2	NA	NA
		CO_2	more effect on RBD	no difference in results
PBSY Vs RBD	B5	O_2	more effect on PBSY	more effect on RBD
		CO	more effect on RBD	no difference in results
		NO	more effect on RBD	more effect on PBSY
		NO_2	more effect on RBD	more effect on PBSY
		NO_X	more effect on RBD	more effect on PBSY
		SO_2	NA	NA
		CO_2	more effect on RBD	more effect on PBSY
PBSY Vs RBD	B10	O_2	more effect on RBD	more effect on RBD
		CO	more effect on PBSY	more effect on PBSY
		NO	more effect on PBSY	more effect on PBSY
		NO_2	more effect on PBSY	more effect on PBSY
		NO_X	more effect on PBSY	more effect on PBSY
		SO_2	NA	NA
		CO_2	more effect on PBSY	more effect on PBSY
PBSY Vs RBD	B20	O_2	more effect on PBSY	more effect on RBD
		CO	more effect on RBD	more effect on PBSY
		NO	more effect on RBD	more effect on PBSY
		NO_2	more effect on RBD	more effect on PBSY
		NO_X	more effect on RBD	more effect on PBSY
		SO_2	NA	NA
		CO_2	more effect on RBD	more effect on PBSY
RBD Vs Diesel	NA	O_2	more effect on diesel	more effect on diesel
		CO	more effect on diesel	more effect on RBD
		NO	more effect on diesel	more effect on RBD
		NO_2	no difference in results	no difference in results
		NO_X	more effect on RBD	no difference in results

		SO_2	no difference in results	no difference in results
		CO_2	more effect on RBD	no difference in results
PBSY Vs Diesel	NA	O_2	more effect on diesel	more effect on diesel
		CO	more effect on PBSY	more effect on PBSY
		NO	more effect on PBSY	no difference in results
		NO_2	more effect on diesel	no difference in results
		NO_X	more effect on diesel	no difference in results
		SO_2	more effect on diesel	no difference in results
		CO_2	more effect on diesel	no difference in results

Exhaust Emission Standards

regulation	exhaust emissions species			
	HC	CO	NO_x	PM
United States 2007 (15 ppm sulfur petrodiesel)	0.14 g/hp h NMHC	15.5 g/hp h	0.20 g/hp h	0.01 g/hp h
Euro IV 2005[b]	0.46 g/kWh	1.5 g/kWh	3.5 g/kWh	0.02 g/kWh
Euro V[b]	0.46 g/kWh	1.5 g/kWh	2.0 g/kWh	0.02 g/kWh

[a] On-highway heavy-duty diesel engines; maximum 15 ppm sulfur in the United States, 10 ppm sulfur in Europe; 1 g/hp-hr = 1.341 g/kWh. [b] Euro IV and V include smoke limited to 0.5 m^{-1}.

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