September 2001 • NREL/SR-540-30163

Subcontractor Report

On-Road Development of John Deere 6081 Natural Gas Engine

Final Technical Report

July 1999—January 2001

D.L. McCaw and W.A. Horrell

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List of Acronyms:

AFUP	Alternate Fuels Utilization Program
BTU	British thermal unit
CARB	California Air Resources Board
CFF	clean fuel fleet
CFFV	clean fuel fleet vehicle
CFR	Code of Federal Regulations
CITT	curb idle transmission torque
CNG	compressed natural gas
CO	carbon monoxide
DF	deterioration factor
DGE	diesel gallon equivalent
DOE	U. S. Department of Energy
DPSG	Deere Power Systems Group
EPA	Environmental Protection Agency
FTP	federal test procedure (for emissions compliance)
hp	horsepower
HPR	high pressure regulator
LEV	low emission vehicle
LHV	lower heating value
mpg	miles per gallon
mph	miles per hour
NGV	natural gas vehicle
NMHC	non methane hydrocarbon
NREL	National Renewable Energy Lab
NO_x	nitrogen oxide
OEM	original equipment manufacturer
PEC	product engineering center
PM	particulate matter
rpm	revolutions per minute
scf	standard cubic feet
SwRI	Southwest Research Institute
WMI	Waste Management of Irvine

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1.0. Executive Summary

The National Renewable Energy Laboratory (NREL) is the field manager for the U.S. Department of Energy (DOE) Alternative Fuels Utilization Program (AFUP). As a result of a competitive solicitation, NREL awarded a contract to John Deere and teamed with them to share the costs of the field development of a heavy-duty natural gas engine.

The field test was conducted in the California South Coast Air Basin, using four engines operating in trash trucks that are part of the Waste Management (WMI) fleet in Orange County. As part of the project, NGV Ecotrans converted four existing trash packers with Peterbilt 320 chassis for compressed natural gas (CNG) fuel systems, and re-powered the trucks with Deere's prototype, spark-ignited 280-hp 8.1 L CNG engines. Two 1999 Volvo trucks with mechanically controlled diesel engines served as diesel control vehicles. These vehicles were field tested by WMI for approximately 12 months in front-loader trash collection in Southern California. This vocation subjects the engine to severe service, which is useful for comprehensively testing the engine's design and validating the engine's performance against a market-leading diesel engine model.

This field development served as a useful step toward commercializing the engine for heavy-duty trucking applications. The core objectives of this program were met or exceeded as follows:

1) The contract called for a minimum of 250 hours durability testing. After meeting the contract requirements, John Deere continued durability testing for an additional 750 hours at their expense.

2) The John Deere 6081 engine power was successfully increased from 250 to 280 HP.

3) The contract called for an engine that could be certified to the 2.5 gm-NO_x standard. The John Deere engine was successfully certified to the lower 2.0 gm-NO_x standard @ 280 HP during this program as follows:

California Air Resources Board (CARB)-Executive Order A-108-22 dated 13 September 2000 certifying to the Optional Low NO_x 2.0 gm standard- The emission standard and certification exhaust emission values for this engine family in grams per brake horsepower-hour under the Federal Test Procedure ("FTP") are:

	Non-Methane Hydrocarbons	Carbon Monoxide	Nitrogen Oxides	Particulate Matter
Standard	1.2	15.5	2.0	0.05
Certification	0.2	1.0	1.8	0.01

Environmental Protection Agency (EPA) - Certificate Number JDX-CFF LEV -01-01 dated 7 September 2000 certifying to:

NO_x + NMHC 3.8 gm Clean Fuel Fleet LEV standard - Federal Fuel
NO_x + NMHC 3.5 gm Clean Fuel Fleet LEV standard - California Fuel

The above results were obtained using an oxidation catalyst.

4) Four 1994 Peterbilt trucks owned by WMI were successfully retrofitted with John Deere natural gas engines.

5) The four retrofitted refuse trucks successfully completed 12 months of in-service fleet use.

6) Three months of mileage and fuel data were gathered for the in-service operations of the four retrofitted trucks and two control diesel trucks in the same fleet. Over the 3-month data collection period for which reliable data was collected, the CNG refuse haulers accumulated an average of 3,205 miles while operating an average of 442 engine hours. The CNG refuse haulers averaged 2.90 miles per diesel equivalent gallon (mi/DGE), compared to an average of 2.68 mi/DGE exhibited by the diesel controls.

John Deere has now released the newly certified engine for full commercial production, making it available for original equipment manufacturers (OEM) use for on-highway applications. Additionally, the successful development of a high horsepower, high efficiency, low emission CNG 6081 Deere engine will provide the basis for further enhancements, such as lower emissions or improved efficiency, and for new programs, like incorporating ion sensing technology, speciation of the exhaust constituents, or new market applications.

2.0. Introduction

The National Renewable Energy Laboratory (NREL) is the field manager for the U.S. Department of Energy (DOE) Alternative Fuels Utilization Program (AFUP).

Deere had been developing and lab testing updates to the current 8.1 natural gas engine with the goal of bringing a new product to the market in the next 1-2 years. The majority of the laboratory work necessary to develop the engine and prepare for on-road development had been successfully completed at SwRI (Southwest Research Institute). The prototype engine configuration was ready for vehicle installation and on-highway testing in customer fleets. As a result of a competitive solicitation, NREL awarded a contract to John Deere and teamed with them to share the costs of this field development of a heavy-duty natural gas engine. The field test was conducted in the California South Coast Air Basin, using four engines operating in trash trucks that are part of the Waste Management (WMI) fleet in Orange County.

The program consisted of multiple tasks, several of which needed to be managed as concurrent projects to meet both the schedule and objectives. The key tasks required to accomplish the program's objectives are:

- Task #1 Completion of Laboratory Engine Development
- Task #2 Procurement of Prototype Engines
- Task #3 Installation of Engines and Fuel Systems
- Task #4 Fleet Operations
- Task #5 Development of Prototype Engines in Service
- Task #6 Commercial Engine Configuration and FTP Test
- Task #7 Environmental, Safety, and Health Compliance

2.1 Project Participants

Participant	Primary Role / Function
John Deere	CNG engine manufacturer
Southwest Research Institute	Performance and emission development, durability testing, and emission certification
NGV Ecotrans	Development vehicle retrofits & repairs
Waste Management of Irvine	Host fleet. Vehicle operation, maintenance, and data collection
Arthur D. Little	Data collection, analysis, and reporting

2.2 Project Objectives

The objective of this project was to develop a John Deere 6081 on-highway, heavy-duty, natural gas engine with the following characteristics:

1) Higher engine ratings (280 rated hp/900 lb-ft peak torque)
2) Meets Environmental Protection Agency Clean Fuel Fleet Vehicle Low Emission Vehicle (EPA CFFV LEV) & California Air Resource Board (CARB) optional low NO_x (2.5 g/hp-hr) emission standards
3) Reduces vehicle cost
4) Develop a low-emission, high performance CNG engine in a Class 8 refuse hauling application side-by-side with diesel control vehicles and document results.

2.3 Fleet Description & Duty Cycle

CNG is potentially attractive for class 8 (>33,000-lb Gross Vehicle Weight) short-haul truck applications where large quantities of fuel are used, vehicles are centrally fueled, and routes contain multiple starts and stops. Refuse hauling matches these criteria well. The CNG demonstration trucks and the control diesel trucks in this field development test were all front load dumpster type refuse trucks. The trucks were used for commercial and industrial refuse hauling, required 50-100 stops per day, and sometimes transported or stopped at businesses within residential areas.

2.4 Reporting Period

This report covers work conducted during the period from July 7, 1999 to January 11, 2001.

3.0. Completion of Laboratory Engine Development (Task #1)

John Deere contracted SwRI to assist in further development and durability testing of the John Deere PowerTech 8.1L natural gas engine to meet the goals of the Natural Gas (NG) Engine Program. John Deere 8.1 L NG engine serial number RG6081H000237 was used for 250 hours of life testing at SwRI, which was included in this contract. This testing is further described in section 3.2.

3.1 Performance and Emissions Development

In previous work, several pistons with a range of compression ratios were tested to determine the best tradeoff in terms of power and efficiency. That work was carried over to this program. Dyno work was performed on the engine to modify the shape of the full load torque curve for the truck application. In particular, the torque curve was changed to increase the torque levels at speeds below 1600 rpm. This work involved an iterative process of adjusting the fuel-air equivalence ratio, spark timing, and boost pressure control set-points to provide the desired torque output. Emissions measurements were also made to ensure the NO_x at the higher torque levels would meet or exceed the 2.5 g/bhp-hr standard requirements.

Dyno work was also conducted to further improve the engine calibration. The boost control table was finalized for the desired torque curve, and the waste-gate control table was modified to ensure that the engine torque response was proportional to the throttle input across the operating range of the engine. The humidity compensation tables were revised for proper operation over the full range of humidity conditions to prevent misfire tendency. Knock testing was conducted and revised gains for the knock control system were developed as a short-term safeguard against engine damage from poor quality gas. The commercial engine will include all of these features.

Woodward Governor Co, Fort Collins, CO, manufactures and supplies natural gas engine control systems for John Deere. Woodward incorporates the specific calibrations developed by John Deere/SwRI for the Deere CNG engines into the control files. Woodward provided the updated files for the previously mentioned revisions in the latest calibration information. Those updated files were then tested at SwRI and found to have the proper correction values.

With the steady state laboratory calibration complete, the next step was to test driveability. Verification of the calibration under transient conditions in an actual vehicle was necessary to truly optimize the calibration. SwRI used a school bus with an updated 8.1 John Deere CNG engine as the driveability vehicle. The initial driveability results were good and this calibration was established as the starting point for testing the refuse fleet.

3.2 Durability Testing

The John Deere 8.1L NG engine serial number RG6081H000237 was used for the life testing at SwRI.

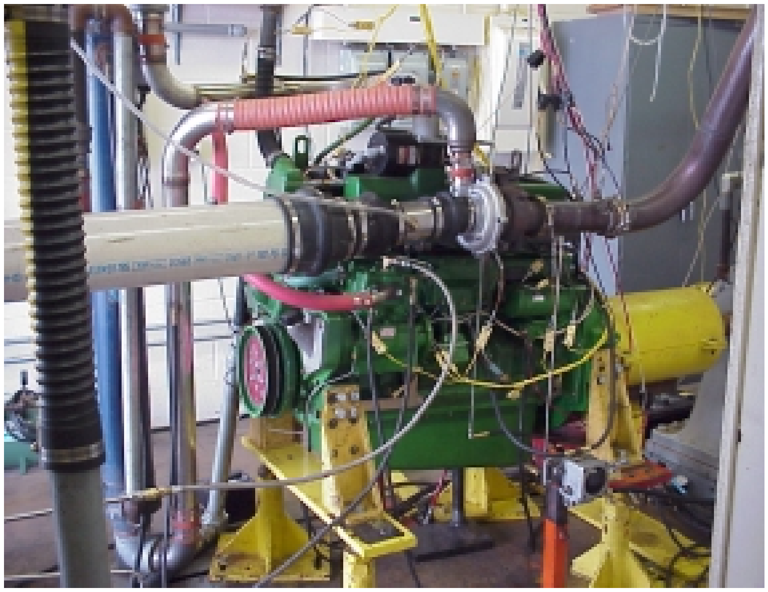


Photo 2.1 - Durability Test Engine Installation

A photograph of the durability test engine as installed in the test cell is shown in Photo 2.1. The engine was instrumented to measure power and fuel flow as well as pertinent temperatures and pressures.

The durability test was started on November 15, 1999. A few minor problems were experienced during the first 100 hours. At 36 test hours, the waste-gate actuator failed. The actuator was replaced and no further problems were noted. At 51 test hours, the exhaust manifold gasket on cylinder #1 was found to be leaking. No damage to the manifold or head was found, so the gasket was replaced and the test continued. At 54 test hours, a slight misfire was noted. The cause was determined to be a poor connection between the ignition coil and the spark plug boot. This was corrected and no further misfires were noted. The spark plugs were examined, valve recession measurements were conducted, and no significant wear was noted.

The John Deere 8.1L NG engine serial number RG6081H000237 completed the 250 hours of life testing without further problems. In addition to the 250 hours that were required and co-funded as part of this program, this engine was run for another 750 hours of life testing at John Deere's expense. Following the 1,000 hours of testing, it was then returned to the John Deere Product Engineering Center for a complete tear down and final inspection. The tear down and inspection of the durability engine following 1,000 hours of life testing found it to be in excellent condition. No major problems of any type were found during tear down inspection or during the suppliers' inspection of the key components from this engine.

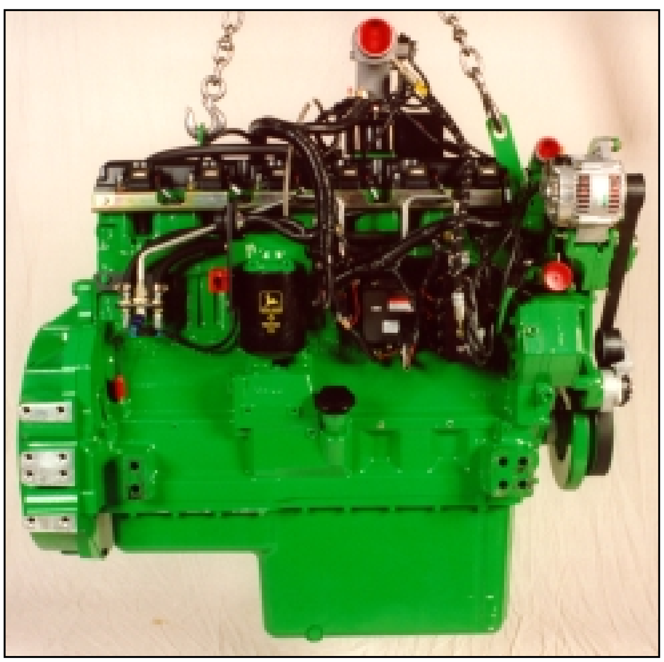
4.0. Procurement of Prototype Engines (Task #2)

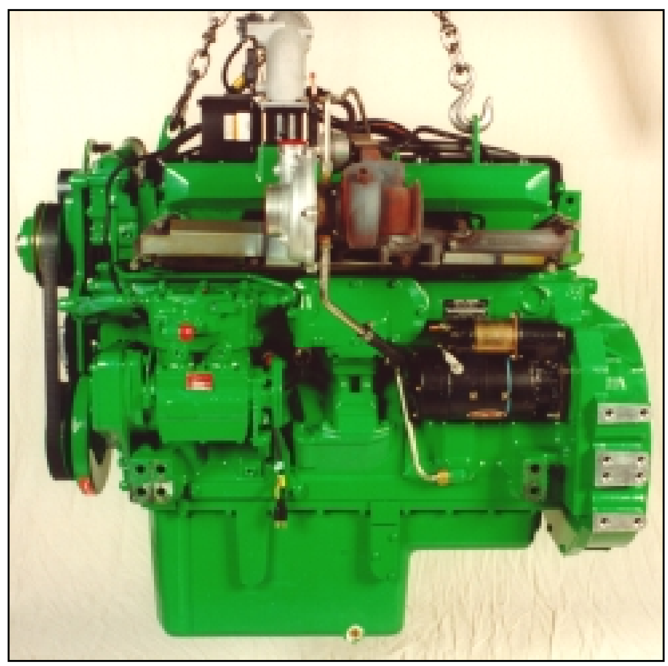
John Deere produced four prototype 8.1L 280HP NG engines for the on-highway testing program. The basic engines were built on the John Deere Engine Works production assembly line. They were then shipped to the John Deere Product Engineering Center (PEC) where they were trimmed for vehicle integration, performance tested, and prepared for shipment to ECOTRANS for installation into the Waste Management trash trucks. In addition, heat rejection, oil consumption, and damper testing was conducted on the first (Serial Number RG6081H066432) engine.

All four engines were then delivered to ECOTRANS for re-power of WMI trucks. The engine serial numbers are as follows;

1) RG6061H066432
2) RG6081H066435
3) RG6081H096215
4) RG6081H096216

Photographs of the 8.1L NG engine configured for this truck application are shown in Photos 4-1 & 4-2.





Photos 4-1 & 4-2. Left-hand and Right-hand Views of the John Deere 8.1L Natural Gas Engine

5.0. Installation of Engines and Fuel Systems (Task #3)

NGV Ecotrans Group in Los Angles, California was contracted by John Deere to retrofit the four on-highway test vehicles.

During August 1999, Ecotrans installed a John Deere natural gas engine S/N RG6081H066432 into the first of four Peterbilt P320 trash truck chassis owned by WMI. The truck was a 1994 model year with 127,853 miles on it. The replaced engine was a Cummins 8.3 L diesel. In addition, Ecotrans fitted this vehicle with four natural gas tanks, modified the Allison transmission to handle higher torque, recored the radiator, and fabricated new engine mounts. Ecotrans also adapted various vehicle systems such as: exhaust, inlet air, and electrical systems to interface with the new engine.

5.1 Initial Driveability

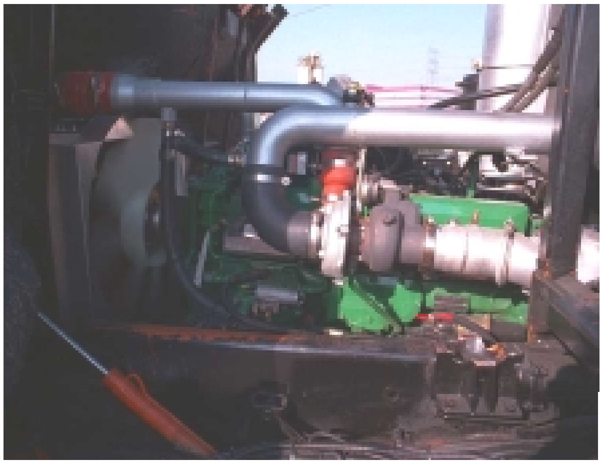
The initial start up of the first vehicle occurred in late August. There were various issues addressed at initial start up. Some slight adjustments to the calibration were completed. These changes minimized the high-speed governor surge, and minor fueling changes were made to improve the tip-in smoothness. After completing these changes, the driveability was considered to be satisfactory, except in the following areas: 1) The acceleration was not quite what the WMI fleet was looking for, and 2) The transmission shifted late.

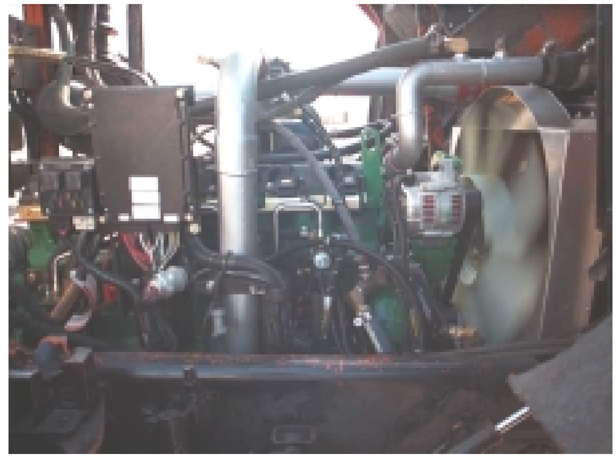
During September, Ecotrans and John Deere worked together to resolve the vehicle performance issues identified during the initial shake-down of the first WMI vehicle. During this process, it was found that the engine misfired at low vehicle speeds. The problem was found to be due to the placement of the exhaust exit very close to the engine air intake. The exhaust system was revised to prevent re-circulation and the engine ran fine.

Investigation of the transmission performance issue found two separate problems: 1) the transmission shifted too late, and 2) the transmission "slipped" during the gear three to four shift. A speed sensor on the transmission was found to be disconnected which solved the late shift problem, and a loose contact for the lock-up torque converter was found which resolved the "slipping" problem. The transmission then operated properly.

In a continuing effort to increase the low speed performance of the engine, John Deere opted to incorporate a different turbocharger. The development of the new turbocharger and engine control calibrations continued during fleet operation. The details of this work are covered in Section 7.0 of this report.

Photographs of the first WMI trash truck following the retrofit with the John Deere 8.1L NG engine are shown in Photos 5-1 through 5-5.





Photos 5-1 & 5-2. Left hand and Right hand Views of the John Deere 8.1L NG Engine in Chassis.

Photos 5-3 & 5-4. Left-hand and Right-hand Views of CNG Tanks Installed on the P320 Trash Truck Chassis Owned by WMI.

Photo 5-5. Left-hand View of WMI Trash Truck Following the Retrofit with a 280 HP John Deere 8.1L CNG Engine

After completing all the checks and changes, the results of the driveability test were considered to be satisfactory. The first vehicle was then delivered to WMI for use in fleet operation. Once the driveability of the first truck was deemed satisfactory by WMI, the remaining three trucks were scheduled for retrofitting at Ecotrans. All of the trucks were Peterbilt P320 chassis with between 125,000 and 135,000 miles on the odometer. Retrofitting of the last truck was completed in March 2000.

Installation of all four engines into trucks was completed by Ecotrans on the Peterbilt P320 trucks owned by WMI, as follows:

Started Service in WMI Fleet	Engine serial numbers	WMI Fleet numbers	VIN Numbers
12 Oct 99	RG6061H066432	Truck #269	1XPZL79X1RD706468
31 Jan 00	RG6081H066435	Truck #203	1XPZX70X4SD708612
19 Feb 00	RG6081H096215	Truck #267	1XPZL79XXRD706467
22 Mar 00	RG6081H096216	Truck #274	1XPZX70X0SD708610

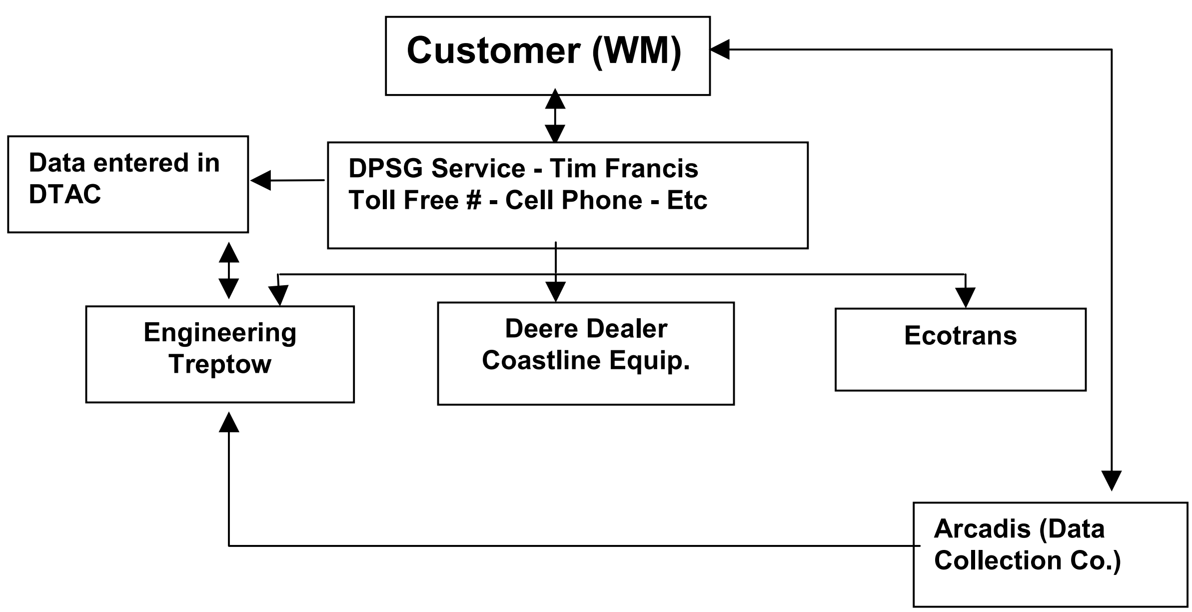
The complete Vehicle Specifications sheets for the four trucks are provided as Attachments 1 through 4.

6.0. Fleet Operations (Task #4)

A formal field testing agreement was established between WMI and John Deere. This agreement defined that ownership of these Pre-certification engines stays with John Deere during the 12-month testing period. It further defined the responsibilities of each party during the testing period for parts, repairs, maintenance, and data reports.

A lower tier-subcontract was signed between Arthur D. Little and John Deere for third party data collection and evaluation. Once all the trucks were retrofitted and full fleet operations began, Arthur D. Little collected data on the four John Deere powered vehicles, and on two similar diesel powered vehicles in the WMI fleet. The two diesel control trucks were 1999 Volvo model WXLL64 with Volvo VED7300 mechanically controlled engines.

A product support plan was established for the John Deere test vehicles in the WMI fleet. The plan was to have the customer contact DPSG Service directly when problems occurred. This kept the information and communication at one common point. Deere Service then analyzed each situation to determine if the problem could be handled by the local Deere dealer or if Ecotrans or Deere Engineering needed to be involved. A flow chart for the product support plan follows:



The following sections present operating data and performance calculations for the program period. This data was independently collected and tabulated by Arthur D. Little, Inc.

6.1 Mileage Accumulation and Utilization

The number of miles and engine hours logged by the trucks differed between CNG and diesel trucks. This was largely a result of various problems with the re-power process and the use of older vehicles and subsequent downtime for the CNG powered vehicles. In general, the CNG and diesel refuse haulers ran similar routes in terms of duty-cycle and mileage. However, beginning in September 2000, CNG truck #203 ran a route to the City of Mission Viejo, resulting in higher mileage and higher average speeds (due to increased highway travel). As of December 4, 2000, WMI entered into an agreement with the City of Mission Viejo to provide refuse removal using only CNG-powered haulers. After December 4, 2000, all available CNG trucks were used in Mission Viejo, thereby achieving duty-cycle parity among CNG vehicles. The diesel control trucks operated in Irvine at slightly lower average speeds.

Tables 6-1and 6-2 present comparisons of cumulative hubodometer and engine hour meter readings for the period of October 5, 2000 to January 11, 2001. It is this time span for which hubodometer and engine hour data was recorded by Arthur D. Little personnel, and CNG fueling data were provided by Pickens Fueling Reports.

Table 6-1. Cumulative Hubodometer Mileage Comparison (5 October 2000–11 January 2001)

WMI Fleet No.	#203	#267[1]	#269	#274	#231	#232
Hubodometer Mileage	3,785	2,332	3,068	3,633	4,865	5,053
Percentage of Diesel[2]	76%	47%	62%	73%	NA	NA

Table 6-2. Cumulative Engine Hour Comparison (5 October 2000–11 January 2001)

WMI Fleet No.	#203	#267[1]	#269	#274	#231	#232
Engine Hours	438	427	452	452	745	769
Percentage of Diesel[2]	59%	56%	60%	60%	NA	NA

Table 6-3 presents a comparison of availability between CNG and diesel trucks. This comparison is based upon data received over the period between October 5, 2000 and January 11, 2001, and utilizes a count of all days for which miles/engine hours were logged, or fueling events were recorded. The CNG trucks were available for use roughly half of the time that the diesel trucks were utilized. The primary problems with the CNG trucks included transmission overheating and

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[1] For truck #267, cumulative hubodometer, engine hour, and average speed data are for the cumulative period 5 October 2000 – 11 January 2001. Fuel consumption and economy calculations are based upon the period 5 October 2000 – 30 November 2000.

[2] Based upon comparison to average of two diesel values.

[3] Based upon the period 5 October 2000 to 11 January 2001 only.

shifting, hydraulic failures, chassis electrical problems, a trash fire in one of the trucks, and a shortage of drivers. Only a small percent to the downtime was related to CNG problems or CNG development application revisions. A complete listing of the failures is provided in section 6.5 in this report

Table 6-3. Comparison of Time in Service for CNG and Diesel Tractors

WMI Fleet No.	#203	#267	#269	#274	#231	#232
Days in Service[3]	39	35	42	41	77	76
Percentage of Diesel[2]	51%	46%	55%	54%	NA	NA

6.2 Fuel Consumption and Efficiency

Table 6-4 presents average fuel economy, and provides comparison to the diesel baseline on an energy equivalent basis. Because diesel fuel is usually measured in gallons, and CNG is usually measured in standard cubic feet (scf) the trucks were compared on a diesel equivalent basis. To do this, the CNG fuel used was converted to Diesel Gallons Equivalent (DGE) using the lower heating value, or BTU value, of the two fuels. The ratio of the lower heating values (LHV) resulted in a conversion factor of 1.129, which was used to obtain the amount of CNG equivalent in heating value to one gallon of diesel fuel.

Table 6-4. WMI CNG Truck Cumulative Fuel Consumption and Economy Data (5 October 2000 – 11 January 2001)

Data Parameter	WMI Fleet No.					
	#203	#267	#269	#274	#231	#232
Fuel Economy (mi/DGE)[4]	3.0	2.3	2.9	3.4	2.6	2.7
Fuel Economy % of Diesel[5]	114%	88%	108%	125%	NA	NA

[4] Conversion of CNG to diesel for fuel-based performance calculations was performed using the LHV for both fuels. Values of 114,264 btu/GGE and 129,015 btu/gal were used for CNG and diesel, respectively.
[5] Based on comparison to average of two diesel values.

This data indicates that, on average, the CNG refuse haulers achieved approximately 9% better fuel economy than the diesel control refuse haulers. Before drawing a decisive conclusion though, the average speed of the truck needs to be taken into consideration. In general, when operating at slow speeds where aerodynamics are not a significant consideration, the slower the average speed (miles per hour), the higher the fuel consumption. This could be due to increased idling time, or more frequent braking and accelerations. However, the slower average speed does not necessarily indicate a lighter duty cycle. In front loader refuse operation the lifting and compaction hydraulics are generally used during each stop, often resulting in an equally demanding duty cycle for the engine. Taking the average speed into consideration, it is more realistic to conclude that the CNG trucks matched or have slightly better fuel economy than the diesel comparison trucks. Comparing Figures 6-1 and 6-2 can reveal a visual indication of the correlation between fuel economy and slow road speed for this demonstration.

Achieving a fuel economy similar to that of diesel engines is possible because of John Deere's spark-ignited natural gas engine technology, which utilizes proprietary, advanced lean burn control technology to improve efficiency and fuel economy. This system precisely and continuously monitors the engine operating conditions. It then automatically makes the necessary adjustments to maintain the engine at optimum performance.

Figure 6-1 presents the fuel economy for the CNG trucks (#203, #267, #269 and #274) and the diesel control trucks (#231 and #232). The CNG trucks averaged 2.90 mpg (DGE) compared to the diesel control trucks that averaged 2.68 mpg.

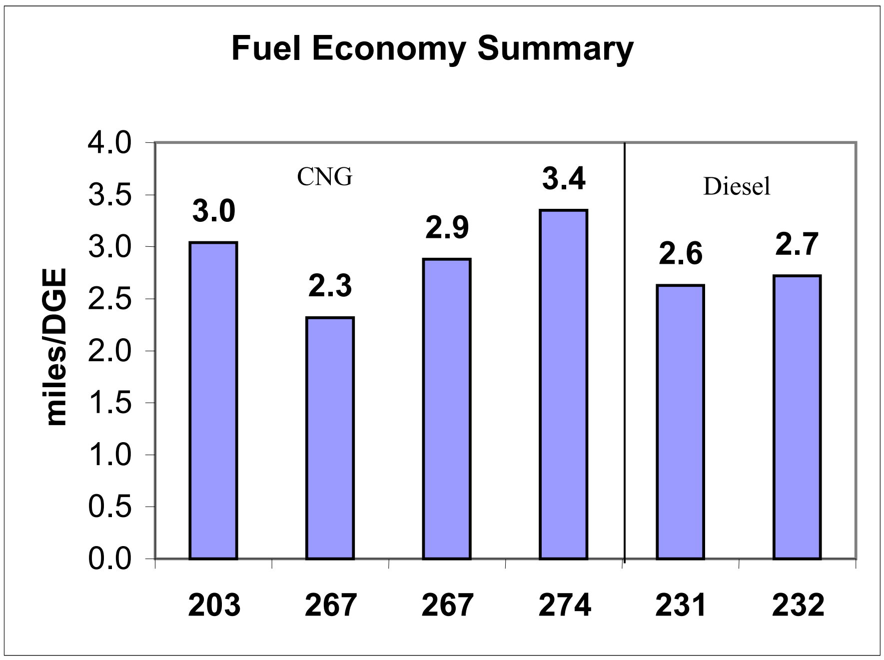


Figure 6-1. Cumulative Fuel Economy Summary

6.3 Average Speed

Figure 6-2 presents average speed calculations for the CNG trucks and the diesel control trucks, on a cumulative basis. Averaging the data reveals the CNG units averaged 7.2 mph and the diesel control units averaged 6.6 mph.

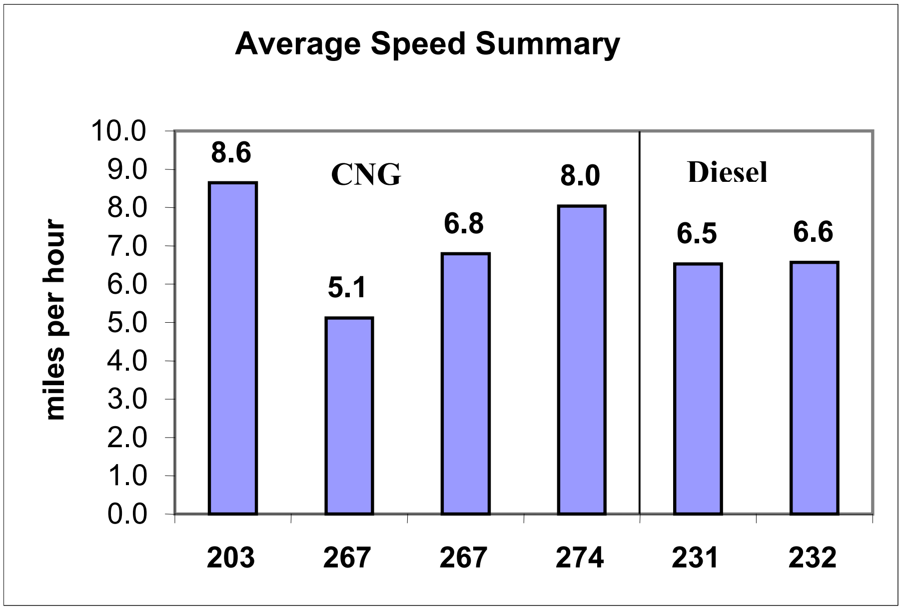


Figure 6-2. Cumulative Average Speed Summary

6.4 Fueling Data Collection

CNG Trucks:

Early in the demonstration, a lack of driver training/input led to improper fueling practices and incomplete fills. Prior to September 2000, it appeared that about 30%–40% of the CNG fills had gone unrecorded. The WMI fleet manager said that this was mainly a result of drivers underfilling the CNG units and then returning for unrecorded "topoff" fills. Drivers had been shuttling the CNG trucks to the City of Irvine CNG station. This light-duty automotive station has a low fill rate, resulting in long (20-30 min.) fill times. Since drivers often work long days (11-13 hrs) and are not given overtime to fill the CNG trucks, incomplete fuel fills often resulted. The trucks then run low on fuel partway through the service day, requiring a trip back to the fueling station. These mid-day fills usually went unrecorded.

An improvement was found when Pickens Fuel Corporation programmed the fueling card readers to accept four-digit hubodometer values. After a period of driver training, hubodometer data capture began at the CNG fueling station. The performance calculations in this report are based on a combination of data collected by Arthur D. Little during WMI site visits, and the fuel reports provided by Pickens.

Diesel Trucks:
Diesel fuel is dispensed at the WMI facility, and tracked using metered reports. These reports are kept on file at WMI, and were provided to Arthur D. Little upon request.

6.5 Refuse Hauler Maintenance and Costs

According to the August 1999 Testing Agreement between Deere and WMI, WMI was responsible for all non-engine and fuel system repairs on the CNG trucks. However, no maintenance records were provided to this end by WMI. The maintenance data in this report was provided by Ecotrans.

Diesel Trucks:
Two diesel powered trucks served as diesel comparison units. The diesel trucks were production 1999 Volvo units with mechanically controlled engines. No maintenance records were received from WMI for inclusion in this report. The shop at WMI presumably handled Diesel maintenance in-house. Due to the lack of diesel maintenance information, no cost comparison can be made with that performed on CNG refuse haulers.

CNG Trucks:
The CNG trucks were 4-5 years older than the diesel control trucks, and would presumably need more maintenance. Also more maintenance might be required because of the experimental nature of the CNG engine. WMI shop staff indicated that very little, if any, maintenance was performed on the CNG trucks by WMI. NGV Ecotrans provided records of work performed on the CNG trucks at their Los Angeles facility. These maintenance and repair events extended well beyond engine and fuel system adjustments and replacements.

Table 6-5 presents maintenance costs associated with repair of both engine and fuel-system-related problems and those that were related to other systems.

Table 6-5. Maintenance Costs Associated with Repairs

	CNG System Related	Other	Total
Total Repairs	1	15	16
% Total Repairs	6.7%	93.3%	100%
Cost	$834	$20,380	$21,214
% Total Cost	3.9%	96.1%	100%

A maintenance situation surfaced at WMI that is typical of new users of the John Deere CNG engine. The WMI service schedule for oil changes has been established by years of experience with diesel engines. When the recommendation of changing the oil at four times the normally established interval was suggested (25,000 miles for this CNG engine), it is not taken seriously. In an effort to illustrate the need for a longer oil change interval, a cooperative oil analysis program was established where the maintenance supervisor had access to the results. Once the customer saw that the oil was still “healthy,” the longer oil change intervals were adopted at WMI. This change eliminated three out of four of their scheduled oil changes and resulted in cost savings.

Table 6-6 summarizes the work performed by NGV Ecotrans. An inspection reveals that most of the work performed was not engine or fuel system related.

Table 6-6. Maintenance Performed by NGV Ecotrans on CNG Refuse Haulers

W.O.#	LIC/UNIT#	Hrs/Miles	CUSTOMER NAME	CONCERN	WORK PERFORMED	IN-DATE	OUT-DATE
3433	5C41619 203	4,877hrs	O.C.W.M./John Deere	No Power to Dash		12/6/00	
2924	5C41619 203	3,775hrs	John Deere O.C.W.M.	CNG leak	No Leaks found	5/3/00	5/3/00
2939	5C41619 203	3,798hrs	John Deere O.C.W.M.	PTO noise	Replaced PTO and hose	5/11/00	5/11/00
2992	5C41619 203	4,000hrs	John Deere O.C.W.M.	No start complaint	Repaired poor connection at batteries	6/8/00	6/8/00
3076	5C41619 203	4,174 hrs	John Deere /O.C.W.M.	Check Engine light/PTO speed	Repaired Switch for PTO	6/30/00	6/30/00
3078	5C41619 203	4,276hrs	John Deere /O.C.W.M.	PTO change for RPM range	Replaced PTO	7/21/00	7/21/00
3253	5C41619 203	- - -	John Deere /O.C.W.M.	Transmission, overheating, shut off	Overhaul transmission, Relocate Exhaust	8/29/00	10/6/00
3350	5C41619 203	- - -	John Deere /O.C.W.M.	Reposition Radiator and Fan	Reposition Fan and Radiator	10/5/00	10/9/00
3404	5C41619 203	- - -	John Deere /O.C.W.M.	Replace HPR	Replaced HPR	11/16/00	11/17/00
3426	5C41619 203	4,850hrs	O.C.W.M./John Deere	Check HPR for venting	replaced defective HPR	11/30/00	12/4/00
2574	4z97620 267	- - -	John Deere O.C.W.M.	Transmission goes into neutral	Replaced transmission connector	3/20/00	3/22/00
2595	4z97620 267	- - -	John Deere O.C.W.M.	Transmission operation	Trans over filled no problem found	3/22/00	3/22/00
2785	4z97620 267	- - -	John Deere O.C.W.M.	Transmission operation	Replaced transmission connector	4/12/00	4/13/00
2923	4z97620 267	129,221	John Deere O.C.W.M.	CNG leak	Removed and replaced 2 fittings	5/3/00	5/3/00
2912	4z97620 267	129,236	John Deere O.C.W.M.	Check engine light on/trans codes	Repaired wiring and VSS sensor	5/8/00	5/10/00
2940	4z97620 267	129,350	John Deere O.C.W.M.	Transmission operation	Repaired damaged wiring harness	5/11/00	5/11/00
3075	4z97620 267	131,287	John Deere /O.C.W.M.	PTO change for RPM range	Replaced PTO	6/30/00	6/30/00
3365	4z97620 267	136,307	John Deere /O.C.W.M.	Check Engine Light	Found codes and misfire, recommend	10/19/00	10/19/00
3376	4z97620 267	136,675	John Deere /O.C.W.M.	Replace Plugs	Replaced plugs and tried to clear codes	10/26/00	10/31/00
3381	4z97620 267	136,675	John Deere /O.C.W.M.	Check Transmission Operation	Connector for transmission	10/31/00	11/6/00
3386	4z97620 267	136,679	John Deere /O.C.W.M.	Repair connector on (trans)	Reconnected wires Bruce installed wrong	11/3/00	11/6/00
3434	4z97620 267	137,713	O.C.W.M./John Deere	Loss of Power and backfire		12/6/00	
2926	5B14827 269	134,608	John Deere O.C.W.M.	CNG leak	No leaks found	5/3/00	5/3/00
2987	5B14827 269	- - -	John Deere O.C.W.M.	Replace power solenoid	Installed water proof box for 12v power	6/5/00	6/5/00
3024	5B14827 269	136,369	John Deere O.C.W.M.	CNG performance	Replaced power sol and box/lock off	6/23/00	6/23/00
3079	5B14827 269	136,831	John Deere /O.C.W.M.	Won't start	Replaced Fuse and Relay module	7/21/00	7/21/00
3425	5B14827 269	142,802	O.C.W.M./John Deere	Replace CNG fill valve	Replaced CNG fill valve	11/30/00	12/4/00
3364	5D17885 274	132,646	John Deere /O.C.W.M.	Transmission noise when hot	Found Rivets missing from fan shroud	10/19/00	10/19/00
3391	5D17885 274	132,483	John Deere /O.C.W.M.	Transmission Operation	Ck trans okay/airway restricted RAD	11/6/00	11/16/00
2925	5D17885 274	126,428	John Deere O.C.W.M.	CNG leak	No Leaks found	5/3/00	5/3/00
2913	5D17885 274	121,428	John Deere O.C.W.M.	Overheating while driving	Replaced coolant reservoir cap	5/8/00	5/8/00
2933	5D17885 274	126,428	John Deere O.C.W.M.	PTO noise and coolant leaking	Replaced coolant reservoir cap	5/10/00	5/10/00
3037	5D17885 274	129,063	John Deere O.C.W.M.	Replace PTO unit	Replaced PTO unit	6/30/00	6/30/00
3317	5D17885 274	131,698	John Deere /O.C.W.M.	Truck overheats	Service call	9/19/00	9/25/00
3336	5D17885 274	131,742	John Deere /O.C.W.M.	Overheating	Found Problem with Transmission	9/29/00	9/29/00
3341	5D17885 274	131,742	John Deere /O.C.W.M.	Coolant system won't cool	Repositioned fan in radiator	10/4/00	10/9/00
3405	5D17885 274	132,491	John Deere /O.C.W.M.	Defective Check Valve	Replaced Check Valve	11/16/00	11/16/00
3432	5D17885 274	- - -	O.C.W.M./John Deere	Transmission no shift	Turbine speed sensor replaced	12/6/00	12/8/00

6.6 Refuse Hauler Fueling Costs

The diesel fuel was purchased at a bulk rate and the CNG was purchased commercially, resulting in a cost differential of $0.14/gallon. The bulk purchased diesel fuel does not have the cost of the tanks, pumping, etc. included, whereas the commercially purchased fuel infrastructure costs are added to the cost of the CNG fuel. If the capital cost and maintenance of the infrastructure were considered for both fuels, their price would be similar on an equivalent energy basis.

Table 6-7. Fuel Cost Calculations

Diesel Truck	Diesel Gallons	Diesel Fuel Cost (@ $1.28/gal)	Miles Driven	Cost / Mile
231	1,848	$2,365	4,865	$0.49 / mile
232	1,856	$2,375	5,053	$0.47 / mile
Total	3,704	$4,740	9,918	$0.48 / mile
CNG Truck	**DGE**	**CNG Fuel Cost (@ $1.42/DGE)**	**Miles Driven**	**Cost / Mile**
203	1,246	$1,765	3,785	$0.47 / mile
267	859	$1,219	2,332	$0.52 / mile
269	1,064	$1,511	3,068	$0.49 / mile
274	1,083	$1,538	3,633	$0.42 / mile
Total	4,252	$6,033	12,818	$0.47 / mile

Diesel Trucks:

Table 6-7 shows diesel fuel amounts used during the demonstration, and during the reporting period of October 5, 2000 to January 11, 2001. Diesel fuel is purchased by WMI in bulk and delivered on site for $1.28/gallon.

CNG Trucks:

Table 6-7 also shows CNG fuel amounts used during the demonstration, and during the reporting period of October 5, 2000 to January 11, 2001. CNG is purchased by WMI from Pickens Fuel Corporation at a commercial outlet for $1.42/DGE.

6.7 Deere Engine and CNG Fuel System Repairs

Based upon maintenance and repair records provided by NGV Ecotrans and John Deere, only two engine or fuel system-related repairs were necessary during the demonstration. The first repair involved failure of the high-pressure regulator (HPR). The HPR is supplied on the engine and is directly related to CNG use. WMI personnel had indicated a gas-like smell emanating from truck #203. NGV Ecotrans identified the source of the gas smell as the pressure regulator. The regulator reduces gas pressure between the vehicle storage tanks and the engine. The regulator includes a pressure release valve, designed to vent a small amount of gas if the regulated pressure for gas being delivered to the engine becomes excessive. This maintains the correct operating pressure required by the engine, but produces the gas smell noticed by WMI personnel. The problem with the regulator was traced to contamination in the relief valve seat, which resulted in gas seepage.

Unrelated to this problem, a higher performance gas regulator was already planned for installation on the WMI trucks. Therefore, Ecotrans replaced the pressure regulator with the new boost-biased pressure regulator. Ecotrans installed a tap in the air intake (downstream of the turbo) that connected to the regulator. One advantage of the new style regulator is that as boost pressure builds with additional power requirements, the regulator increases the gas pressure to provide the necessary fuel for that load. In other words, under boost conditions more fuel can be supplied via the regulator.

The second problem involved what was first believed to be blown head gasket on truck #267 but was found to be improper intake air filtration. In December, Ecotrans reported white smoke coming from the exhaust and an engine misfire. They also noticed smoke and oil between the cylinder head and engine block on the driver's side of the engine. The engine was removed and sent to John Deere Engine Works to be disassembled and inspected. The inspection showed no signs of a head gasket failure. There was severe knock damage to piston #1, debris damage to the compressor of the turbocharger, abnormal wear on the top compression rings and cylinder liners, and fine particle debris in the air intake system. Based on the inspection, it appears that the intake air was not properly filtered. The resulting debris caused damage to the compressor wheel of the turbocharger and caused the cylinder liners and top compression rings to wear abnormally. The excessive wear of rings and liners caused high oil consumption, which led to a knock condition. The engine controller in this vehicle did not have the knock sensing capabilities of the production controller, so it was not able to retard the spark timing or set an engine fault code. There was also no record indicating drivers taking corrective action for knocking conditions. This allowed knocking to occur, causing severe damage to piston #1 and a significant decrease in cylinder pressure, misfire, and white smoke as reported by Ecotrans. Improper intake air filtration would have caused the same result with a diesel engine, therefore it was not charged as a CNG specific failure in this report. The cause of this failure was improper maintenance and was not CNG related.

The oil and smoke coming from the driver's side of the engine was most likely due to a failed exhaust manifold gasket combined with high oil consumption and misfire. A similar exhaust manifold gasket failure occurred on the life test engine. This gasket problem has been corrected by changing the fastener material.

6.8 Driveability and Performance

One key factor in assessing the commercial viability for CNG-fueled refuse haulers is how drivers perceive their performance compared to the diesel vehicle they normally operate. Driver input is also important because drivers are usually the first to detect a problem in the system. The general practice by WMI is to assign multiple drivers to its various diesel-fueled refuse haulers. For the CNG refuse hauler demonstration, a different system was set up. In the interest of minimizing variability and maximizing safety and data collection effectiveness, WMI assigned a select few drivers to operate the CNG refuse haulers. For the most part, one particular driver exclusively operated a particular CNG refuse hauler.

The WMI drivers were satisfied with the driveability and performance of the CNG trucks. One change they requested was for the compactor speed to be matched to that of the conventional, diesel-fueled haulers.

7.0. Development of Prototype Engines in Service (Task #5)

Once the on-highway testing was underway, John Deere worked with the trucking fleet to overcome any performance, reliability, or durability problems that were experienced. SwRI was sub-contracted to assist John Deere with any engine calibration work needed to resolve field problems.

To address the problem related to slower than desired acceleration for the first 1-2 seconds and improve torque at lower engine speeds, a new Garrett turbocharger was selected. A prototype of this new turbocharger configuration was first run on a lab engine at SwRI to verify design expectations. This change improved the low-end torque of the engine. At the same time, by increasing the airflow at low speeds, the calibration could be modified to operate the engine at leaner air/fuel ratios. The result was an engine with slightly lower emissions due to leaner operation. In the vehicle, the new turbocharger greatly reduced the lag but did not totally eliminate it during acceleration from a complete stop.

To see how the performance was affected in the truck, new control calibrations were installed on the truck engines. These calibrations modified the shape of the full load torque curve on the engine at lower operating speeds. In particular, the torque curve was changed to increase the torque levels at speeds below peak torque. The actual torque increase varied with engine speed, but at engine speeds below 1600 rpm the torque increased from 2% to16%.

WMI had requested that the hydraulic pump speed for the compactor be matched to that of the conventional, diesel-fueled haulers. Improved operation of the trucks was obtained by raising the engine's optional idle speed from 1100 rpm to 1300 rpm. The engine controller software was reprogrammed for that revision. This change increased the hydraulic pump speed to a more acceptable level, but not quite to the expectations of the operators based on previous experience.

8.0. Commercial Engine Configuration and FTP Test (Task #6)

One objective of the demonstration program was to have a production engine certified to the 2.5 g/bhp-hr Optional Low NOx emissions standard for CARB. During initial engine development results were close enough to a lower target that further research was justified to actually reach the lower target. The following paragraphs describe the process involved and the final certification to the 2.0 g/bhp-hr Optional Low NOx emissions standard.

The development emissions targets as well as the CARB Low NO_x standards are shown in Table 8-1. These development targets were calculated based on the standards requirements, deterioration factors, and a margin for engine build variability.

Table 8-1. Emissions Targets for Development (units in g/bhp-hr)

Pollutant	Abbreviation	Development Target	CARB Low NO_x Standard
Nitrogen oxides	NO_x	1.840	2.5
Nonmethane hydrocarbons	NMHC	1.080	1.2
Carbon monoxide	CO	2.800	15.5
Particulate matter	PM	0.045	0.05

8.1 Test Preparations

The transient emissions tests were conducted according to the EPA Federal Test Procedure (FTP), as specified in the Code of Federal Regulations (CFR), Title 40, Part 86, Subpart N. For all tests, the curb idle transmission torque (CITT) was set to 70 lb-ft. The test fuel used for emissions testing was blended to meet the CARB specifications for a certification fuel blend. The composition of the blended fuel, as measured by gas chromatographic analysis, is shown in Table 8-2.

Table 8-2. Fuel Used for Emissions Testing

Component	Concentration (%)
C_1 (Methane)	90.69
C_2 (Ethane + Ethylene)	3.74
C_{3+} (Propane)	1.96
Inerts (Nitrogen)	3.61

The engine was equipped with a Woodward Governor Company gas engine management system. The latest revision of the John Deere 280 hp software from Woodward Governor Company was downloaded into flash memory of the controller. This software was used without modification for all the test runs for emissions certification purposes. The engine was also equipped with an oxidation catalyst, except where noted.

8.2 Performance Results:

Power validation runs were conducted to verify that the engine was operating correctly and to ensure that all the test cell conditions, such as inlet and exhaust restrictions, etc. were correct. A summary of parameters measured during the power validation is listed in Table 8-3.

Table 8-3. Performance Results from Power Validation

Parameter		Rated Power	Peak Torque
Speed	rpm	2200	1600
Torque	lb-ft	681	929
Power	bhp	285	283
Fuel Flow	lb/hr	94.1	89.3
Intake Restriction	in. H_2O	-8.00	-7.10
Exhaust Restriction	in. Hg	2.00	1.83
Intake Air Temperature	°F	72	69
Intake Air Dew Point	°F	61.9	61.2
ΔP across Intercooler	in. H_2O	27.20	12.24

A torque map was generated by operating the engine at wide-open throttle from 600 rpm to 2400 rpm. A plot of the full load torque curve for the test engine is shown below in Figure 8-1.

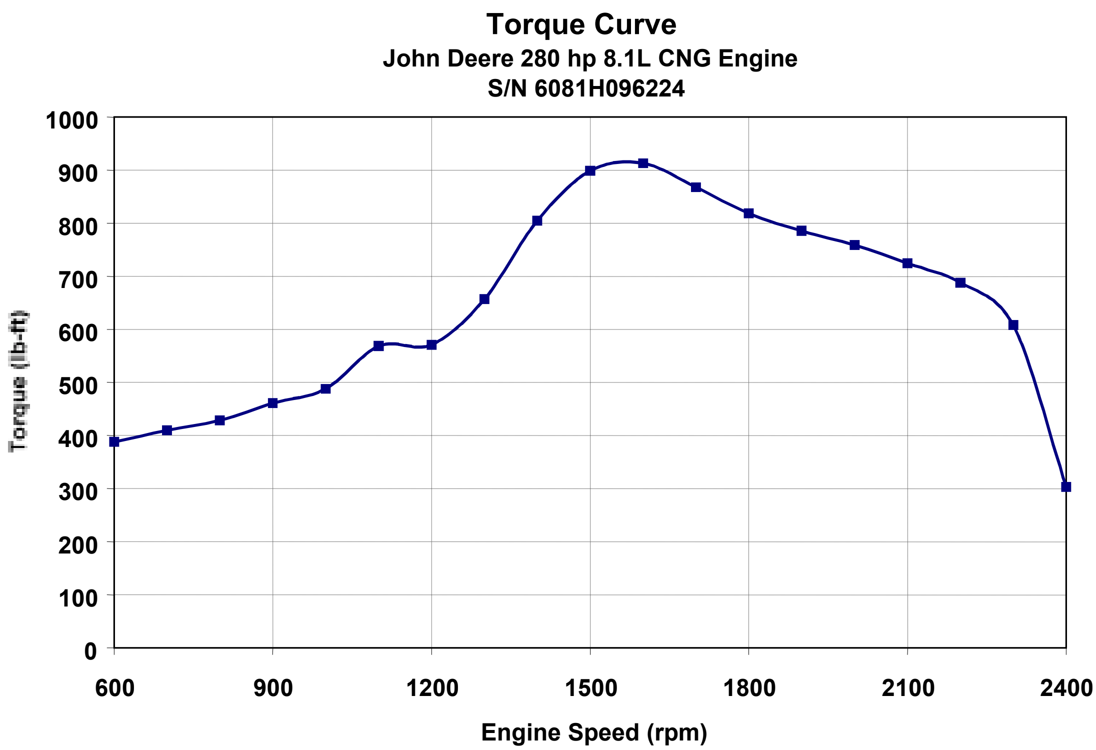


Figure 8-1. Torque Curve for 280 Hp John Deere 8.1L Natural Gas Engine

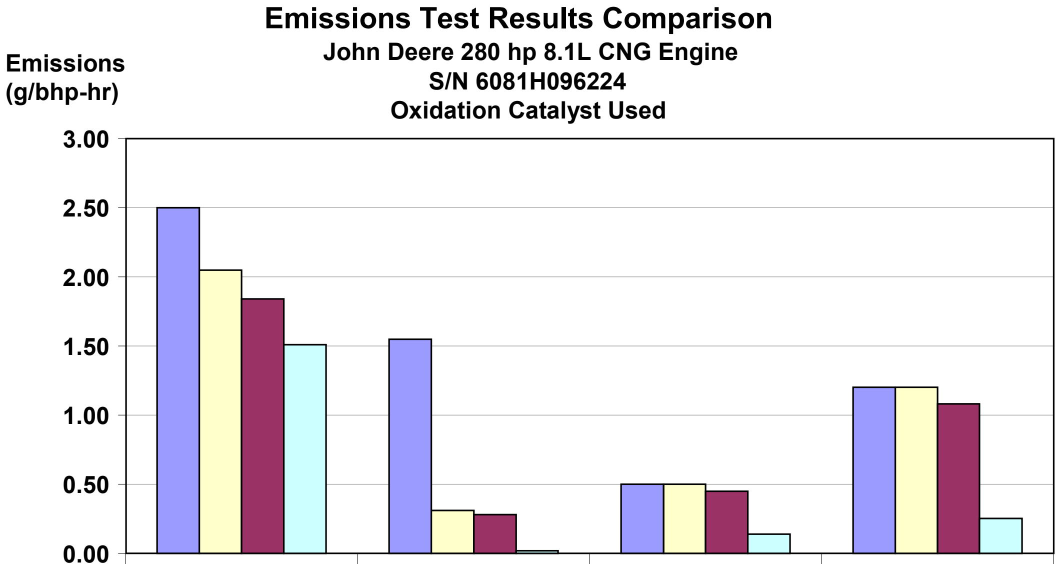
Following completion of the torque map, several practice cycles were conducted to tune the test cell controller so that the engine would pass cycle statistics reliably and to verify that the engine was operating correctly.

8.2.1 Emissions Results With Catalytic Aftertreatment

Transient emissions testing of the 280 hp certification test engine was completed at SwRI after the development work was complete. Calibration work was conducted to achieve the target NO_x level of 1.84 g/bhp-hr out of the engine in order to have compliance with the 2.5 emissions standard. The engine was equipped with an oxidation catalyst and operated on a CARB CNG certification fuel blend. A cold start/hot start test sequence was conducted. The engine's actual performance enabled Deere to certify to 2.0 g NO_x rather that the original target of 2.5 g NO_x.

The composite test results for this configuration are shown in Figure 8-2. Results for NO_x, CO, nonmethane hydrocarbons (NMHC), and particulate matter (PM) are shown. The composite test results are a weighted average, with the cold start weighting factor equal to 1/7 and the hot-start weighting factor equal to 6/7. Note that the bars in the graph are scaled for graphical clarity, i.e., the CO emissions bar is divided by a factor of 10 and the particulate emissions bar is multiplied by a factor of 10. For comparison purposes, a data table is included in Figure 8-2 that shows some reference emissions values in addition to the actual measured value; the numbers in the data table are <u>not</u> scaled.

The first reference value is the emissions limit as dictated by the appropriate CARB optional 2.5 Low NO_x standard development target. The second reference value is the limit level adjusted to reflect the effect of the 2900 hour useful life deterioration factor (DF). The third reference value is the calibration target for certification. This number is a percentage of the DF-adjusted value and provides a margin to account for engine variability. As can be seen in Figure 8-2, the actual engine emissions easily meet the development target levels and are significantly lower than the 2.5 Low NO_x standard. As expected, NO_x had the closest margin. For the other emissions (CO, PM, and NMHC), the actual levels were significantly lower than the target values.

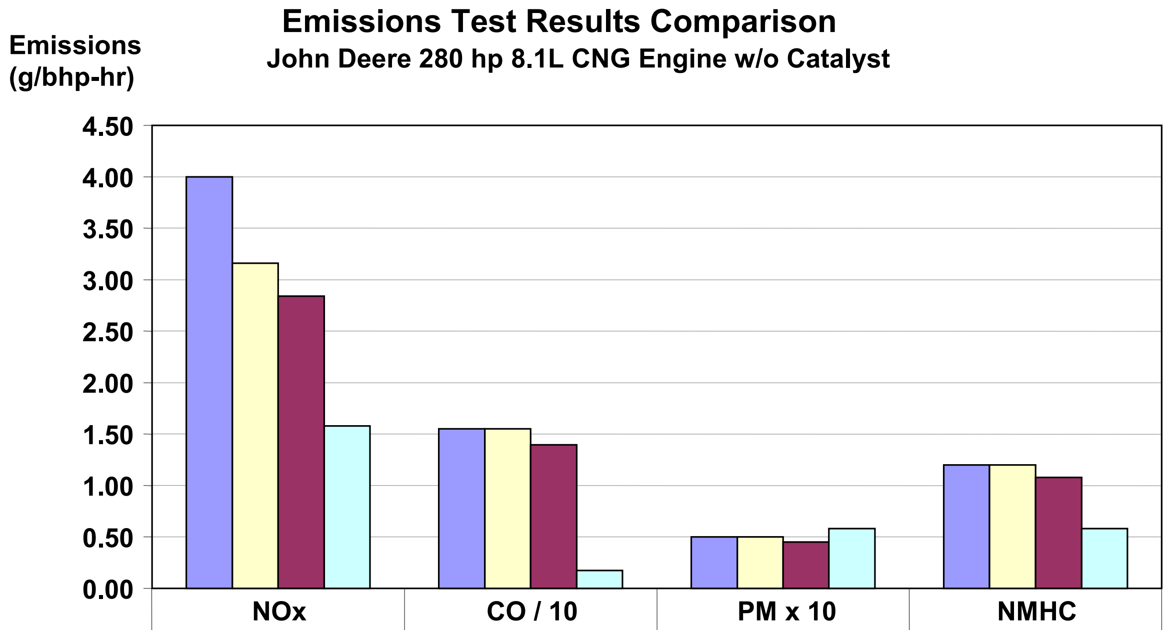


	NOx	CO / 10	PM x 10	NMHC
Standard	2.50	15.5	0.050	1.20
DF-Adj.	2.05	3.1	0.050	1.20
Target	1.84	2.8	0.045	1.08
Actual	1.51	0.2	0.014	0.25

Figure 8-2. Composite Emissions Results for Engine Equipped with an Oxidation Catalyst

8.2.2 Emissions Results Without Catalytic Aftertreatment

Following the successful completion of these tests, the catalyst was removed from the engine for additional testing with no aftertreatment. The same calibration developed for the catalyst-equipped engine was used, since it was anticipated that the calibration developed for this application also allowed the engine to meet the EPA 4.0 g/bhp-hr NO_x on-highway truck standard. The exhaust restriction was adjusted at rated conditions to provide equivalent backpressure to that obtained with the catalyst. A cold start/hot start test sequence was subsequently conducted. Composite test results for these tests were plotted relative to the EPA Heavy Duty Diesel Engine standards for trucks and urban buses and are shown in Figure 8-3.



	NOx	CO / 10	PM x 10	NMHC
Standard	4.00	15.5	0.050	1.20
DF-Adj.	3.16	15.5	0.050	1.20
Target	2.84	14.0	0.045	1.08
Actual	1.58	1.8	0.056	0.58

Figure 8-3. Composite Emissions Results for the Engine without an Oxidation Catalyst

Tests confirmed that this engine configuration could easily achieve the 4.0 g/bhp-hr NO_x standard. All other emissions were below the target value except for particulate matter, which exceeded the regulated level by approximately 12%. Higher than usual oil consumption was suspected to be the cause of the PM problem. A review of the oil consumption records during the catalyst aging cycle confirmed that the engine had a higher than expected oil consumption rate. An earlier version of the 280-hp engine demonstrated PM in the range of 0.020-0.025 g/bhp-hr, roughly one-half of the results shown here for the official certification tests. It is expected that the PM emissions will be below the target value when the engine is equipped with production cylinder liners rather than prototype liners.

8.3 Conclusions

Significant achievements of the field development of the John Deere CNG engine included:

- The power of the John Deere 8.1 CNG engine was increased from 250 to 280 hp.
- The John Deere 8.1 CNG engine demonstrated fuel efficiency on par with the diesel control trucks.
- The emissions testing described in this report confirmed that the engine performed well and produced relatively low levels of emissions. Specifically, the testing showed:
  1) The engine achieved the CARB Optional 2.0 Low NO_x emissions standards when equipped with an oxidation catalyst
  2) The engine achieved the EPA Heavy Duty truck standards for 2004 without the use of catalytic aftertreatment.
  3) With the exception of particulate matter emissions, the engine can achieve the EPA urban bus standards without the use of catalytic aftertreatment.
- John Deere produces the 280 hp Low NO_x 8.1 CNG engine for OEM applications.

8.4 Certification Results

John Deere has received the on-highway emission certifications on the John Deere 6081 Compressed Natural Gas Engine at 280 HP for model year 2001 as follows:

CARB - Executive Order A-108-22 dated 13 September 2000 certifying to the Optional Low NO_x 2.0 gm standard. The emission standard and certification exhaust emission values for this engine family in grams per brake horsepower-hour under the Federal Test Procedure ("FTP") are:

	Non-Methane Hydrocarbons	Carbon Monoxide	Nitrogen Oxides	Particulate Matter
Standard	1.2	15.5	2.0	0.05
Certification	0.2	1.0	1.8	0.01

EPA - Certificate Number JDX-CFF LEV -01-01 dated 7 September 2000 certifying to:

NO_x + NMHC 3.8 gm Clean Fuel Fleet LEV standard - Federal Fuel
NO_x + NMHC 3.5 gm Clean Fuel Fleet LEV standard - California Fuel

9.0. Environmental, Safety, and Health Compliance (Task #7)

All work performed on this project has been conducted in ways that conform with applicable federal, state, and local environmental, safety, and health codes and regulations.

Truck #274 had a fire in trash compaction unit on morning of August 3, 2000. The truck was parked over night in the WMI lot with a full load of compacted trash. The fire is believed to have started in the trash due to spontaneous combustion. The fire was put out quickly and damage was limited to the body of the compaction unit. The paint on the cargo body was badly damaged and truck was out of service for stripping & re-painting. There was no damage to the engine, fuel systems, controls, or CNG fuel tanks.

10.0. Future Plans

John Deere has released the newly certified engine for full commercial production, making it available for OEM on-highway applications. In addition, the success demonstrated and the knowledge gained during this program has demonstrated the feasibility of proceeding with future programs to pursue further reductions in natural gas engine emission levels.

Improvement of the oil consumption rate will be required to reduce the particulate matter emissions below 0.050 g/bhp-hr. Similar John Deere CNG engines produce significantly lower levels of PM, so a detailed study of the differences in oil control hardware between the production engine, the earlier development 280 hp engine, and the current production 280 hp will be made. Additional emissions testing of an engine with improved oil control systems are planned in the near future. This will allow certification of the engine to the lowest possible PM standards.

Attachment # 1

Sections 9.0 Vehicle Specifications

Vehicle Specifications for John Deere/NREL Subcontract No ZCI-9-18055-03 (16Aug2000)

VEHICLE SPECIFICATIONS

Form Revised 1/12/96

HDV VEH Table

Vehicle ID Number (VIN)	Vehicle identification number	IXPZX70X4SD708612
Fleet Veh ID	Vehicle identification number used by fleet	# 203
Vehicle Make	Name of vehicle manufacturer	Peterbilt
Vehicle Model	Truck model number	P320
Vehicle Year	Year vehicle was manufactured	1994
Service Date	Date vehicle was put into service by fleet	31 January 2000
Start Mileage	Mileage on vehicle at the start of the fleet demonstration	135,303
Activity Code	Type of activity vehicle is used for (Code 1 from VMRSH)	Refuse (code L1)
Equipment Category Code	Type of optional equipment installed on vehicle	N/C
Body Mfgr Code	Name of body manufacturer	Universal Refuge
Body Descr Code	Type of body attached to cab (Code 48 from VMRSH)	Trash Compactor (code 254)
Engine Serial	Serial number of the engine	RG6081H066435

HDV ENGINE Table

OEM – Retrofit	Is the engine OEM or a retrofit?	Retrofit
Eng Mfgr Code	Name of engine manufacturer	John Deere
Eng Model	Engine model number	6081H
Eng Config Code	Engine Configuration Code (Code 35 from VMRSH)	In-line 6 cylinder (code 12)
Eng Cu In	Engine size in cubic inches	496 (8.1L)
Num Cylinders	Number of cylinders	6
Eng Year	Year engine was manufactured	1999
Cycle	Is the engine 2 cycle or 4 cycle ?	4
Compr Ratio	Compression ratio	11:1
Ignition Aid Type	Type of ignition aids used	None
EPA Certified (Y/N)	Is the engine configuration EPA certified	No (Certification testing is Scheduled)

Maximum bHp	Rated maximum brake horsepower of engine	280
Rpm of Max bHp	Rpm at rated maximum brake horsepower	2200
Maximum Torque (ft-lbs)	Rated maximum torque of engine	900 lb-ft
Rpm of Max Torque	Rpm at rated maximum torque	1600
Oil Capacity (qts)	Oil capacity in quarts	24
Blower? (Y/N)	Does the engine have a blower?	No
Turbocharger? (Y/N)	Does the engine have a turbocharger?	Yes

HDV FUEL SYSTEMS Table

Fuel Type Code	What type of fuel is engine designed for?	CNG
Diesel Additives	Type of additives used in diesel fuel	NA
Alt Fuel Additives	Type of additives used in alternative fuel	None
Mech Elec	For liquid fuel engines, are the injectors mechanically or electronically controlled?	NA
Injector Mfr	Name of liquid fuel injector manufacturer	NA
Inj Model	Liquid fuel injector model number	NA
Num of Injectors	Number of liquid fuel injectors	NA
Liq-Fuel Filter Mfr	Name of liquid fuel filter manufacturer	NA
Liq-Fuel Filter Model	Liquid fuel filter model number	NA
Fuel Induction	For gaseous fuel engines, is it injection or fumigation?	Injection
Air Intake Throttle (Y/N)	Does the engine use an air intake throttle	Yes
Gas Equip (OEM/Retrofit)	Is the gas fuel system OEM or retrofit?	Engine OEM, vehicle tanks Retrofit
Number of Alt Fuel Tanks	Number of alternative fuel tanks	4
Number of Diesel Tanks	Number of diesel tanks	NA
AF Max Work Press (psi)	Alternative fuel maximum working pressure in psi	3500
Amount of Useable AF	Total useful alternative fuel in tank(s)	7,148 SCF @ 3600 psi
Alt Fuel Units	Units used for alternative fuel tank(s) useful volume	SCF + standard cubic feet
Amount of Useable Diesel	Total useful diesel fuel in tank(s)	NA
Diesel Fuel Units	Units used for diesel fuel tank(s) useful volume	NA
AF Tank Manufacturer	Name of alternative fuel tank(s) manufacturer	Lincoln (2) 18.4" x 78", SCI (2) 12" X 60"
Diesel Tank Manufacturer	Name of diesel fuel tank(s) manufacturer	NA
Alt Fuel Tank Model	Alternative fuel tank(s) model number	Lincoln (R240057-113), SCI (CS12.06036)
Diesel Tank Model	Diesel fuel tank(s) model number	NA

Alt Fuel Empty Tank Wt	Alternative fuel tank(s) empty weight	820 lbs
Alt Fuel Tank Wt Units	Units used for alternative fuel tank(s) empty weight	Lbs = Pounds
Diesel Empty Tank Wt	Diesel fuel tank(s) empty weight	NA
Diesel Tank Wt Units	Units used for diesel fuel tank(s) empty weight	NA

HDV TRANS Table

Transmission Mfr	Name of transmission manufacturer	Allison
Trans Model Number	Transmission model number	MD3066
Trans Year of Mfr	Transmission year of manufacture	1999
Trans Type Code	Type of Transmission (Code 7 from VMRSH)	Automatic (code 2)
Forward Speeds	Number of forward speeds	5
Reverse Speeds	Number of reverse speeds	1

HDV AXLE Table

Axle Type Code	Type of axle configuration (Code 3 from VMRSH)	8 wheels, 4 driven wheels (code G)
Axle Front Weight	Axle front weight	
Front Tire Size	Size of front tire	315/80 R 22.5
Rear Tire Size	Size of rear tires	315/80 R 22.5
Axle Mfgr Code	Name of drive axle manufacturer (from VMRSH)	Eaton
Axle Model	Drive axle model number	R402F
Rear Axle Config Code	Rear axle configuration (Code 37 from VMRSH)	Single Speed, Single Reduction (code 1)
Rear Axle Setup Code	Setup of rear axle configuration (Code 38 from VMRSH)	Tandem (code 2)
Axle Ratio Low	Low axle ratio	NA
Axle Ratio High	High axle ratio	5.57:1
Total GVW Wt (lb)	Total gross vehicle weight in pounds	50,000
Total Curb Wt (lb)	Total weight with the truck in curb weight configuration	17,460
Torque Converter Ratio	Torque converter ratio	1.98:1
Wheelbase	Length of wheelbase	168” to the front rear axle, 233” to the rear, rear axle

HDV EMISSION Table

Cat Conv	Does the vehicle have a catalytic converter? Y or N	No
Cat Conv Mfg	Name of catalytic converter manufacturer.	NA
Cat Conv Model	Model number of the catalytic converter.	NA
Dsl Prt Trap	Does the vehicle have a diesel particulate trap? Y or N	NA
Trap Mfg	Name of the particulate trap manufacturer.	NA
Trap Model	Model number of the particulate trap.	NA
Trap Regen_Type	Type of trap regeneration process	NA
Trap Conf	Particulate trap configuration	NA
Num Trap Ele	Number of particulate trap elements	NA
Trap Sys Wt	Weight of the particulate trap system	NA

Attachment # 2

Sections 9.0 Vehicle Specifications

Vehicle Specifications for John Deere/NREL Subcontract No ZCI-9-18055-03 (16Aug2000)

VEHICLE SPECIFICATIONS

Form Revised 1/12/96

HDV VEH Table

Vehicle ID Number (VIN)	Vehicle identification number	IXPZL79XXRD706467
Fleet Veh ID	Vehicle identification number used by fleet	# 267
Vehicle Make	Name of vehicle manufacturer	Peterbilt
Vehicle Model	Truck model number	P320
Vehicle Year	Year vehicle was manufactured	1994
Service Date	Date vehicle was put into service by fleet	19 February 2000
Start Mileage	Mileage on vehicle at the start of the fleet demonstration	127,857
Activity Code	Type of activity vehicle is used for (Code 1 from VMRSH)	Refuse (code L1)
Equipment Category Code	Type of optional equipment installed on vehicle	N/C
Body Mfgr Code	Name of body manufacturer	Universal Refuge
Body Descr Code	Type of body attached to cab (Code 48 from VMRSH)	Trash Compactor (code 254)
Engine Serial	Serial number of the engine	RG6081H096215

HDV ENGINE Table

OEM – Retrofit	Is the engine OEM or a retrofit?	Retrofit
Eng Mfgr Code	Name of engine manufacturer	John Deere
Eng Model	Engine model number	6081H
Eng Config Code	Engine Configuration Code (Code 35 from VMRSH)	In-line 6 cylinder (code 12)
Eng Cu In	Engine size in cubic inches	496 (8.1L)
Num Cylinders	Number of cylinders	6
Eng Year	Year engine was manufactured	1999
Cycle	Is the engine 2 cycle or 4 cycle ?	4
Compr Ratio	Compression ratio	11:1
Ignition Aid Type	Type of ignition aids used	None

EPA Certified (Y/N)	Is the engine configuration EPA certified	No (Certification testing is Scheduled)
Maximum bHp	Rated maximum brake horsepower of engine	280
Rpm of Max bHp	Rpm at rated maximum brake horsepower	2200
Maximum Torque (ft-lbs)	Rated maximum torque of engine	900 lb-ft
Rpm of Max Torque	Rpm at rated maximum torque	1600
Oil Capacity (qts)	Oil capacity in quarts	24
Blower? (Y/N)	Does the engine have a blower?	No
Turbocharger? (Y/N)	Does the engine have a turbocharger?	Yes

HDV FUEL SYSTEMS Table

Fuel Type Code	What type of fuel is engine designed for?	CNG
Diesel Additives	Type of additives used in diesel fuel	NA
Alt Fuel Additives	Type of additives used in alternative fuel	None
Mech Elec	For liquid fuel engines, are the injectors mechanically or electronically controlled?	NA
Injector Mfr	Name of liquid fuel injector manufacturer	NA
Inj Model	Liquid fuel injector model number	NA
Num of Injectors	Number of liquid fuel injectors	NA
Liq-Fuel Filter Mfr	Name of liquid fuel filter manufacturer	NA
Liq-Fuel Filter Model	Liquid fuel filter model number	NA
Fuel Induction	For gaseous fuel engines, is it injection or fumigation?	Injection
Air Intake Throttle (Y/N)	Does the engine use an air intake throttle	Yes
Gas Equip (OEM/Retrofit)	Is the gas fuel system OEM or retrofit?	Engine OEM, vehicle tanks Retrofit
Number of Alt Fuel Tanks	Number of alternative fuel tanks	4
Number of Diesel Tanks	Number of diesel tanks	NA
AF Max Work Press (psi)	Alternative fuel maximum working pressure in psi	3500
Amount of Useable AF	Total useful alternative fuel in tank(s)	7,148 SCF @ 3600 psi
Alt Fuel Units	Units used for alternative fuel tank(s) useful volume	SCF + standard cubic feet
Amount of Useable Diesel	Total useful diesel fuel in tank(s)	NA
Diesel Fuel Units	Units used for diesel fuel tank(s) useful volume	NA
AF Tank Manufacturer	Name of alternative fuel tank(s) manufacturer	Lincoln (2) 18.4” x 78”, SCI (2) 12” X 60”
Diesel Tank Manufacturer	Name of diesel fuel tank(s) manufacturer	NA
Alt Fuel Tank Model	Alternative fuel tank(s) model number	Lincoln (R240057-113), SCI (CS12.06036)

Diesel Tank Model	Diesel fuel tank(s) model number	NA
Alt Fuel Empty Tank Wt	Alternative fuel tank(s) empty weight	820 lbs
Alt Fuel Tank Wt Units	Units used for alternative fuel tank(s) empty weight	Lbs = Pounds
Diesel Empty Tank Wt	Diesel fuel tank(s) empty weight	NA
Diesel Tank Wt Units	Units used for diesel fuel tank(s) empty weight	NA

HDV TRANS Table

Transmission Mfr	Name of transmission manufacturer	Allison
Trans Model Number	Transmission model number	MD3066
Trans Year of Mfr	Transmission year of manufacture	1999
Trans Type Code	Type of Transmission (Code 7 from VMRSH)	Automatic (code 2)
Forward Speeds	Number of forward speeds	5
Reverse Speeds	Number of reverse speeds	1

HDV AXLE Table

Axle Type Code	Type of axle configuration (Code 3 from VMRSH)	8 wheels, 4 driven wheels (code G)
Axle Front Weight	Axle front weight	
Front Tire Size	Size of front tire	315/80 R 22.5
Rear Tire Size	Size of rear tires	315/80 R 22.5
Axle Mfgr Code	Name of drive axle manufacturer (from VMRSH)	Eaton
Axle Model	Drive axle model number	R402F
Rear Axle Config Code	Rear axle configuration (Code 37 from VMRSH)	Single Speed, Single Reduction (code 1)
Rear Axle Setup Code	Setup of rear axle configuration (Code 38 from VMRSH)	Tandem (code 2)
Axle Ratio Low	Low axle ratio	NA
Axle Ratio High	High axle ratio	5.57:1
Total GVW Wt (lb)	Total gross vehicle weight in pounds	50,000
Total Curb Wt (lb)	Total weight with the truck in curb weight configuration	17,460
Torque Converter Ratio	Torque converter ratio	1.98:1
Wheelbase	Length of wheelbase	168” to the front rear axle, 233” to the rear, rear axle

HDV EMISSION Table

Cat Conv	Does the vehicle have a catalytic converter? Y or N	No
Cat Conv Mfg	Name of catalytic converter manufacturer.	NA
Cat Conv Model	Model number of the catalytic converter.	NA
Dsl Prt Trap	Does the vehicle have a diesel particulate trap? Y or N	NA
Trap Mfg	Name of the particulate trap manufacturer.	NA
Trap Model	Model number of the particulate trap.	NA
Trap Regen_Type	Type of trap regeneration process	NA
Trap Conf	Particulate trap configuration	NA
Num Trap Ele	Number of particulate trap elements	NA
Trap Sys Wt	Weight of the particulate trap system	NA

Attachment # 3

Sections 9.0 Vehicle Specifications

Vehicle Specifications for John Deere/NREL Subcontract No ZCI-9-18055-03 (16 Nov 1999)

VEHICLE SPECIFICATIONS

Form Revised 1/12/96

HDV VEH Table

Vehicle ID Number (VIN)	Vehicle identification number	IXPZL79X1RD706468
Fleet Veh ID	Vehicle identification number used by fleet	# 269
Vehicle Make	Name of vehicle manufacturer	Peterbilt
Vehicle Model	Truck model number	P320
Vehicle Year	Year vehicle was manufactured	1994
Service Date	Date vehicle was put into service by fleet	12 October 1999
Start Mileage	Mileage on vehicle at the start of the fleet demonstration	127,853
Activity Code	Type of activity vehicle is used for (Code 1 from VMRSH)	Refuse (code L1)
Equipment Category Code	Type of optional equipment installed on vehicle	N/C
Body Mfgr Code	Name of body manufacturer	Universal Refuge
Body Descr Code	Type of body attached to cab (Code 48 from VMRSH)	Trash Compactor (code 254)
Engine Serial	Serial number of the engine	RG6081H066432

HDV ENGINE Table

OEM – Retrofit	Is the engine OEM or a retrofit?	Retrofit
Eng Mfgr Code	Name of engine manufacturer	John Deere
Eng Model	Engine model number	6081H
Eng Config Code	Engine Configuration Code (Code 35 from VMRSH)	In-line 6 cylinder (code 12)
Eng Cu In	Engine size in cubic inches	496 (8.1L)
Num Cylinders	Number of cylinders	6
Eng Year	Year engine was manufactured	1999
Cycle	Is the engine 2 cycle or 4 cycle ?	4
Compr Ratio	Compression ratio	11:1
Ignition Aid Type	Type of ignition aids used	None
EPA Certified (Y/N)	Is the engine configuration EPA certified	No (Certification testing is Scheduled)

Maximum bHp	Rated maximum brake horsepower of engine	280
Rpm of Max bHp	Rpm at rated maximum brake horsepower	2200
Maximum Torque (ft-lbs)	Rated maximum torque of engine	900 lb-ft
Rpm of Max Torque	Rpm at rated maximum torque	1600
Oil Capacity (qts)	Oil capacity in quarts	24
Blower? (Y/N)	Does the engine have a blower?	No
Turbocharger? (Y/N)	Does the engine have a turbocharger?	Yes

HDV FUEL SYSTEMS Table

Fuel Type Code	What type of fuel is engine designed for?	CNG
Diesel Additives	Type of additives used in diesel fuel	NA
Alt Fuel Additives	Type of additives used in alternative fuel	None
Mech Elec	For liquid fuel engines, are the injectors mechanically or electronically controlled?	NA
Injector Mfr	Name of liquid fuel injector manufacturer	NA
Inj Model	Liquid fuel injector model number	NA
Num of Injectors	Number of liquid fuel injectors	NA
Liq-Fuel Filter Mfr	Name of liquid fuel filter manufacturer	NA
Liq-Fuel Filter Model	Liquid fuel filter model number	NA
Fuel Induction	For gaseous fuel engines, is it injection or fumigation?	Injection
Air Intake Throttle (Y/N)	Does the engine use an air intake throttle	Yes
Gas Equip (OEM/Retrofit)	Is the gas fuel system OEM or retrofit?	Engine OEM, vehicle tanks Retrofit
Number of Alt Fuel Tanks	Number of alternative fuel tanks	4
Number of Diesel Tanks	Number of diesel tanks	NA
AF Max Work Press (psi)	Alternative fuel maximum working pressure in psi	3500
Amount of Useable AF	Total useful alternative fuel in tank(s)	7,148 SCF @ 3600 psi
Alt Fuel Units	Units used for alternative fuel tank(s) useful volume	SCF + standard cubic feet
Amount of Useable Diesel	Total useful diesel fuel in tank(s)	NA
Diesel Fuel Units	Units used for diesel fuel tank(s) useful volume	NA
AF Tank Manufacturer	Name of alternative fuel tank(s) manufacturer	Lincoln (2) 18.4” x 78”, SCI (2) 12” X 60”
Diesel Tank Manufacturer	Name of diesel fuel tank(s) manufacturer	NA
Alt Fuel Tank Model	Alternative fuel tank(s) model number	Lincoln (R240057-113), SCI (CS12.06036)
Diesel Tank Model	Diesel fuel tank(s) model number	NA

Alt Fuel Empty Tank Wt	Alternative fuel tank(s) empty weight	820 lbs
Alt Fuel Tank Wt Units	Units used for alternative fuel tank(s) empty weight	Lbs = Pounds
Diesel Empty Tank Wt	Diesel fuel tank(s) empty weight	NA
Diesel Tank Wt Units	Units used for diesel fuel tank(s) empty weight	NA

HDV TRANS Table

Transmission Mfr	Name of transmission manufacturer	Allison
Trans Model Number	Transmission model number	MD3066
Trans Year of Mfr	Transmission year of manufacture	1999
Trans Type Code	Type of Transmission (Code 7 from VMRSH)	Automatic (code 2)
Forward Speeds	Number of forward speeds	5
Reverse Speeds	Number of reverse speeds	1

HDV AXLE Table

Axle Type Code	Type of axle configuration (Code 3 from VMRSH)	8 wheels, 4 driven wheels (code G)
Axle Front Weight	Axle front weight	
Front Tire Size	Size of front tire	315/80 R 22.5
Rear Tire Size	Size of rear tires	315/80 R 22.5
Axle Mfgr Code	Name of drive axle manufacturer (from VMRSH)	Eaton
Axle Model	Drive axle model number	R402F
Rear Axle Config Code	Rear axle configuration (Code 37 from VMRSH)	Single Speed, Single Reduction (code 1)
Rear Axle Setup Code	Setup of rear axle configuration (Code 38 from VMRSH)	Tandem (code 2)
Axle Ratio Low	Low axle ratio	NA
Axle Ratio High	High axle ratio	5.57:1
Total GVW Wt (lb)	Total gross vehicle weight in pounds	50,000
Total Curb Wt (lb)	Total weight with the truck in curb weight configuration	17,460
Torque Converter Ratio	Torque converter ratio	1.98:1
Wheelbase	Length of wheelbase	168” to the front rear axle, 233” to the rear, rear axle

HDV EMISSION Table

Cat Conv	Does the vehicle have a catalytic converter? Y or N	No
Cat Conv Mfg	Name of catalytic converter manufacturer.	NA
Cat Conv Model	Model number of the catalytic converter.	NA
Dsl Prt Trap	Does the vehicle have a diesel particulate trap? Y or N	NA
Trap Mfg	Name of the particulate trap manufacturer.	NA
Trap Model	Model number of the particulate trap.	NA
Trap Regen_Type	Type of trap regeneration process	NA
Trap Conf	Particulate trap configuration	NA
Num Trap Ele	Number of particulate trap elements	NA
Trap Sys Wt	Weight of the particulate trap system	NA

Attachment # 4

Sections 9.0 Vehicle Specifications

Vehicle Specifications for John Deere/NREL Subcontract No ZCI-9-18055-03 (16Aug2000)

VEHICLE SPECIFICATIONS

Form Revised 1/12/96

HDV VEH Table

Vehicle ID Number (VIN)	Vehicle identification number	IXPZX70X0SD708610
Fleet Veh ID	Vehicle identification number used by fleet	# 274
Vehicle Make	Name of vehicle manufacturer	Peterbilt
Vehicle Model	Truck model number	P320
Vehicle Year	Year vehicle was manufactured	1994
Service Date	Date vehicle was put into service by fleet	22 March 2000
Start Mileage	Mileage on vehicle at the start of the fleet demonstration	125,670
Activity Code	Type of activity vehicle is used for (Code 1 from VMRSH)	Refuse (code L1)
Equipment Category Code	Type of optional equipment installed on vehicle	N/C
Body Mfgr Code	Name of body manufacturer	Universal Refuge
Body Descr Code	Type of body attached to cab (Code 48 from VMRSH)	Trash Compactor (code 254)
Engine Serial	Serial number of the engine	RG6081H096216

HDV ENGINE Table

OEM – Retrofit	Is the engine OEM or a retrofit?	Retrofit
Eng Mfgr Code	Name of engine manufacturer	John Deere
Eng Model	Engine model number	6081H
Eng Config Code	Engine Configuration Code (Code 35 from VMRSH)	In-line 6 cylinder (code 12)
Eng Cu In	Engine size in cubic inches	496 (8.1L)
Num Cylinders	Number of cylinders	6
Eng Year	Year engine was manufactured	1999
Cycle	Is the engine 2 cycle or 4 cycle ?	4
Compr Ratio	Compression ratio	11:1
Ignition Aid Type	Type of ignition aids used	None
EPA Certified (Y/N)	Is the engine configuration EPA certified	No (Certification testing is Scheduled)

Maximum bHp	Rated maximum brake horsepower of engine	280
Rpm of Max bHp	Rpm at rated maximum brake horsepower	2200
Maximum Torque (ft-lbs)	Rated maximum torque of engine	900 lb-ft
Rpm of Max Torque	Rpm at rated maximum torque	1600
Oil Capacity (qts)	Oil capacity in quarts	24
Blower? (Y/N)	Does the engine have a blower?	No
Turbocharger? (Y/N)	Does the engine have a turbocharger?	Yes

HDV FUEL SYSTEMS Table

Fuel Type Code	What type of fuel is engine designed for?	CNG
Diesel Additives	Type of additives used in diesel fuel	NA
Alt Fuel Additives	Type of additives used in alternative fuel	None
Mech Elec	For liquid fuel engines, are the injectors mechanically or electronically controlled?	NA
Injector Mfr	Name of liquid fuel injector manufacturer	NA
Inj Model	Liquid fuel injector model number	NA
Num of Injectors	Number of liquid fuel injectors	NA
Liq-Fuel Filter Mfr	Name of liquid fuel filter manufacturer	NA
Liq-Fuel Filter Model	Liquid fuel filter model number	NA
Fuel Induction	For gaseous fuel engines, is it injection or fumigation?	Injection
Air Intake Throttle (Y/N)	Does the engine use an air intake throttle	Yes
Gas Equip (OEM/Retrofit)	Is the gas fuel system OEM or retrofit?	Engine OEM, vehicle tanks Retrofit
Number of Alt Fuel Tanks	Number of alternative fuel tanks	4
Number of Diesel Tanks	Number of diesel tanks	NA
AF Max Work Press (psi)	Alternative fuel maximum working pressure in psi	3500
Amount of Useable AF	Total useful alternative fuel in tank(s)	7,148 SCF @ 3600 psi
Alt Fuel Units	Units used for alternative fuel tank(s) useful volume	SCF + standard cubic feet
Amount of Useable Diesel	Total useful diesel fuel in tank(s)	NA
Diesel Fuel Units	Units used for diesel fuel tank(s) useful volume	NA
AF Tank Manufacturer	Name of alternative fuel tank(s) manufacturer	Lincoln (2) 18.4" x 78", SCI (2) 12" X 60"
Diesel Tank Manufacturer	Name of diesel fuel tank(s) manufacturer	NA
Alt Fuel Tank Model	Alternative fuel tank(s) model number	Lincoln (R240057-113), SCI (CS12.06036)
Diesel Tank Model	Diesel fuel tank(s) model number	NA

Alt Fuel Empty Tank Wt	Alternative fuel tank(s) empty weight	820 lbs
Alt Fuel Tank Wt Units	Units used for alternative fuel tank(s) empty weight	Lbs = Pounds
Diesel Empty Tank Wt	Diesel fuel tank(s) empty weight	NA
Diesel Tank Wt Units	Units used for diesel fuel tank(s) empty weight	NA

HDV TRANS Table

Transmission Mfr	Name of transmission manufacturer	Allison
Trans Model Number	Transmission model number	MD3066
Trans Year of Mfr	Transmission year of manufacture	1999
Trans Type Code	Type of Transmission (Code 7 from VMRSH)	Automatic (code 2)
Forward Speeds	Number of forward speeds	5
Reverse Speeds	Number of reverse speeds	1

HDV AXLE Table

Axle Type Code	Type of axle configuration (Code 3 from VMRSH)	8 wheels, 4 driven wheels (code G)
Axle Front Weight	Axle front weight	
Front Tire Size	Size of front tire	315/80 R 22.5
Rear Tire Size	Size of rear tires	315/80 R 22.5
Axle Mfgr Code	Name of drive axle manufacturer (from VMRSH)	Eaton
Axle Model	Drive axle model number	R402F
Rear Axle Config Code	Rear axle configuration (Code 37 from VMRSH)	Single Speed, Single Reduction (code 1)
Rear Axle Setup Code	Setup of rear axle configuration (Code 38 from VMRSH)	Tandem (code 2)
Axle Ratio Low	Low axle ratio	NA
Axle Ratio High	High axle ratio	5.57:1
Total GVW Wt (lb)	Total gross vehicle weight in pounds	50,000
Total Curb Wt (lb)	Total weight with the truck in curb weight configuration	17,460
Torque Converter Ratio	Torque converter ratio	1.98:1
Wheelbase	Length of wheelbase	168” to the front rear axle, 233” to the rear, rear axle

HDV EMISSION Table

Cat Conv	Does the vehicle have a catalytic converter? Y or N	No
Cat Conv Mfg	Name of catalytic converter manufacturer.	NA
Cat Conv Model	Model number of the catalytic converter.	NA
Dsl Prt Trap	Does the vehicle have a diesel particulate trap? Y or N	NA
Trap Mfg	Name of the particulate trap manufacturer.	NA
Trap Model	Model number of the particulate trap.	NA
Trap Regen_Type	Type of trap regeneration process	NA
Trap Conf	Particulate trap configuration	NA
Num Trap Ele	Number of particulate trap elements	NA
Trap Sys Wt	Weight of the particulate trap system	NA

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