sierra research

SURVEY OF HEAVY-DUTY DIESEL ENGINE REBUILDING, RECONDITIONING, AND REMANUFACTURING PRACTICES

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

OVERVIEW

During the past two decades, efforts to reduce the contribution of motor vehicle emissions to air pollution have focused principally on the development of emission standards and certification procedures for new vehicles. Despite the significant reduction in emissions achieved by light-duty vehicles in recent years, motor vehicles remain a major source of air pollution in California. Current regulatory efforts to reduce motor vehicle emissions are focused on two areas:

- the operation of an inspection and maintenance (I/M) program for light-duty vehicles to ensure that, as these vehicles age, the emissions reductions observed at certification are maintained; and

- the development of more stringent emission standards for heavy-duty diesel engines and the evaluation of the benefits of an I/M program for heavy-duty diesel vehicles (HDDV's).

Emissions from HDDV's are an important contributor to violations of health-based ambient air quality standards for nitrogen dioxide and inhalable particles in California. The emission standards in force today for these vehicles are substantially less stringent than those of light duty vehicles; regulatory efforts are currently underway to further reduce the emissions of new HDDV's.

Unlike light-duty engines, most of the mileage accumulated on HDDV's occurs after the engine has received its first major overhaul. This is a major source of concern to the Air Resources Board for the following reasons:

- Equipment changes made during the rebuilding or remanufacturing process can substantially degrade emissions performance.

- Because of the differences between California and federal emissions regulations, there is both acceleration and fuel economy performance degradation for vehicles certified to California standards. This degradation is suspected of influencing owners to request that California engines be rebuilt to the federal specifications or to use parts that improve performance but increase emissions levels.

- The long lifespan of HDDV's ensures that several rebuilds are likely to occur and that several opportunities for increasing emissions are available.

- The rebuilding process is unregulated, and the rate of occurrence of improper rebuilds is unknown.

- The influence of new HDDV regulations on air quality levels is diminished by the longer lifespan of older higher emitting HDDV's and the possibility that the emissions of these vehicles may be increased in the rebuilding process.

- In addition, there is a concern that sales of rebuilt, reconditioned, or remanufactured heavy-duty diesel engines, which do not conform with California certification requirements, may be a significant source of excess emissions.

Because of the concerns outlined above, this study was designed to determine the emissions impact of the rebuilding process on California heavy-duty diesel engines. It also addresses the emissions impact of the sales of rebuilt, reconditioned and remanufactured engines in California.

To aid the reader in better understanding the information presented in this report, a brief definition of the primary rebuilding categories is provided. The nomenclature used to describe the range of possible repairs to heavy-duty diesel engines is not exact and frequently some of the terms are used interchangeably.

Rebuilding - covers a broad range of repairs that can occur over the useful life of the engine. These repairs range from the replacement of broken parts to a thorough disassembly, inspection and replacement of parts based on the number of miles or hours of service that an engine has experienced and the procedures recommended by manufacturers for engines with that level of service. Generally, rebuilding is divided into two categories - in-frame and out-of-frame. The in-frame occurs with the engine in the vehicle, which consequently limits the range of inspections and repairs. Normally, this type of rebuild occurs early in an engine life. The out-of-frame requires that the engine be removed from the truck and placed on a stand. The range of inspections and repairs possible in this process is far more extensive than with an in-frame rebuild. This type of rebuild occurs later in an engine's life when more extensive repairs are required.

Reconditioning - generally covers the range of repairs that occur in the rebuilding process.

Remanufacturing - at the end of its useful economic life (additional rebuilds are no longer cost effective), an engine is sent to a manufacturing facility and all parts are stripped from the block. These parts are segregated according to function, cleaned, inspected and either repaired or scrapped. Subassemblies (e.g., turbochargers, fuel injection pumps, oil pumps, etc.) are also torn down to their component parts and follow the same process. The block is then rebuilt with either new or reconditioned equipment. The engine that emerges from this process is unlikely to have any of the parts that it entered the factory with, they have either been discarded or incorporated into a different engine after repair.

Surveys and site visits were used to collect information on the following issues:

1. the size of the heavy-duty engine rebuilding, reconditioning, and remanufacturing industry;

2. the engine upgrading or rebuilding, reconditioning, and remanufacturing practices used, noting any difference between California and federal rebuilding practices;

3. the number of rebuilt, reconditioned, and remanufactured engines (federal and California) sold in California.

To gain a better understanding of the industry and its practices, information was collected on the following subjects:

- typical mileage on engines at the time of rebuilding;

- sources of engines/components (new OEM versus aftermarket);

- rebuild, recondition, and remanufacture practices (California or federal certification, upgrade of components, use of OEM or aftermarket replacement components, etc.);

- specifications for major wear components used in the rebuild, recondition, and remanufacture process that are likely to influence emissions;

- quality control procedures used, including emissions tests;

- procedures for the identification of reconditioned engines;

- sales volume of HDDV's in California and nationwide;

- engine retail prices;

- engine and emission control system warranties; and

- expected useful life of reconditioned, rebuilt and remanufactured engines.

After collecting and analyzing the data, an estimate of the emissions impacts of heavy-duty diesel engine rebuilding practices was produced.

APPROACH

To facilitate data collection, the project was divided into the following six task areas:

- identify the emission critical parts replaced during the rebuild procedure;

- target data collection efforts to selected segments of the rebuilding industry;

- design questionnaires that solicit relevant information from the selected market segments;

- identify survey samples for each of the selected market segments;

- execute the surveys; and

- compile respondent data and analyze the results.

In the first task, the available literature was reviewed to identify engine parts serviced or replaced during the rebuild process that could influence emissions. To augment the literature search, major heavy-duty engine manufacturers were contacted for their views on the emission critical parts and the procedures used in the rebuilding process that might affect emissions. The collection of this information was considered critical to the development of the survey questionnaires.

At the outset of the project, we recognized that there are several distinct segments in the rebuild industry. To form an accurate picture of the practices occurring in the industry, we decided to develop questionnaires that solicited information on the procedures and performance of each industry segment. The segments are:

- Association of Diesel Specialists - a professional organization with an international membership, members specialize in the repair of diesel fuel injection equipment, governors and turbocharger systems;

- heavy-duty vehicle fleets - representing the largest segment of heavy-vehicle ownership, this group includes for-hire vehicles, as well as those that satisfy corporations' internal transportation needs; the size of the individual fleets ranges from less than 10 to several thousand vehicles, the sophistication the service departments varies widely;

- independent rebuild shops - outside of the very large fleets, rebuild shops represent the primary source of available rebuilding expertise, most shops are affiliated with one or more engine manufacturers;

- aftermarket parts suppliers - due to concern raised at the outset of the study that aftermarket parts are inferior in quality and lower in price when compared to OEM parts and could be a source of excess emissions for heavy-duty diesels, a telephone survey of selected suppliers was conducted;

- remanufacturers - operate a production line that strips incoming "spent" engines down to the block and inspect, repair or replace all components, a telephone survey of all known rebuilders supplying engines to California was conducted;

- site surveys - were conducted at the locations of selected questionnaire respondents to interpret the results of data collected in the survey and to gain a better understanding of the processes involved.

The segmentation of the rebuilding industry allowed the preparation of shorter, more specific questionnaires; it also increased the response rate of those surveyed by presenting a less onerous information request.

Concerns about gaining access to fleet maintenance/rebuild shops led to the hiring of an industry consultant, Mr. Lou Hoffman. A former rebuilding shop superintendent for PIE, Mr. Hoffman used his extensive contacts to conduct the survey of the fleets. He also provided insight into questionnaire responses.

To help develop easily understood questionnaires, we prepared and distributed test questionnaires to a series of California rebuilding firms. On the basis of the responses received to that survey, numerous changes were made to the format of questions and information requested in the other questionnaires.

An extensive effort was mounted to identify mailing lists of the selected industry segments. In some cases, this was quite easy as the names of engine manufacturers are well known, and mailing lists were readily available from professional associations. In other cases, professional associations refused to cooperate and forced the development of alternative survey samples. These alternatives included reviews of manufacturer parts and service directories and time-consuming reviews of telephone directories.

To maximize the response rate to the surveys, we included inducements to return questionnaires. Inducements included free magazine subscriptions, summaries of survey responses, and telephone calls to remind/request participation. When responses remained low for a particular industry segment (e.g., California shops that work on fuel injection equipment), follow-up telephone calls were made to all non-respondents, and their responses to the critical questions were collected over the phone. A summary of the non-telephone surveys is presented below:

SUMMARY OF REBUILD SURVEYS

Group Surveyed	Survey Size	Useful Responses	Response Rate
California (test)	48	16	35%
Association of Diesel Specialists	158	42	27%
Fleet Managers	80	44	55%
Rebuild Shops	466	50	11%
Engine Manufacturers	4	4	100%

The information contained in the responses was computerized at the completion of each survey. A separate analysis of each of the surveys was conducted, and responses to common questions were compared for consistency. Inconsistencies noted in the responses were followed up through telephone contacts and field surveys.

The translation of the information collected in the surveys into an estimate of the incremental emissions impact on the fleet of heavy-duty diesel vehicles was divided into the following steps:

- the emissions impact of incorrect rebuild practices for emission critical parts was estimated through a review of available data, conversations with manufacturers, and engineering judgment;

- the rate of occurrence for each incorrect rebuild practice was estimated from the survey data to produce three scenarios that bounded the range of probable experience;

- the estimates of rate of occurrence were combined with estimates of the percentage emissions impact to generate the average emissions impact in gms/BHP-hr by model year 1977-1986 engines.

The estimates of model year emissions impacts were then combined with available estimates of HDDV travel for 1986 to estimate the tons/day impact of improper rebuilding practices.

SUMMARY OF SURVEY RESULTS

Size of the Rebuilding Industry

Data collected from engine manufacturers, the predominant force in the remanufacturing industry, indicated that less than 5 percent of the engine sales occurring in California in 1984 and 1985 were remanufactured. The remanufactured engines are required to achieve the same emission certification levels that they met when they were new. Insufficient data were available to estimate the number of rebuilds conducted on California certified engines in each of the recent calendar years.

Rebuild Frequency and Useful Life

From a regulatory perspective, one of the most important questions related to HDDV's is how long, on average, do they last, and what is their useful life? Data on the number of miles an average heavy-duty engine travels before it is too worn to repair, and the average number of rebuilds it will receive, were collected from rebuild shops across the country. On the basis of approximately 40 responses to this question, we found that an average engine receives 4 rebuilds and travels slightly more than 1 million miles in its lifetime.

Rebuild Costs

A large body of data was collected on the cost of rebuilds from every group surveyed in this study. Results were compared from three viewpoints: fleets; rebuild shops; and manufacturers. Generally, the responses were consistent: the cost of an in-frame rebuild is substantially less than the cost of an out-of-frame for medium-heavy and heavy-heavy duty diesel engines. In all cases, the cost of rebuild was substantially less than the cost of a new engine. The average cost of an in-frame rebuild of a heavy-duty diesel engine is estimated to be approximately 40 percent of the cost of a new engine. The cost of an out-of-frame rebuild is estimated to be approximately 65 percent of the cost of a new engine.

Discussions with engine remanufacturers indicated that the cost of their engines was typically in the range of 65 to 70 percent of new engine prices. Given the more extensive cleaning, inspection and replacement procedures followed in the remanufacturing process, the higher cost is not unexpected. The economies of scale with these operations, however, dampen the cost increment above the rebuilding process.

Data on the mileage accumulated between rebuilds were also collected. It shows that the rebuilds are cost effective, because the increase in engine life from a rebuild is very high. The increased mileage that comes from the first in-frame rebuild for a heavy-duty engine is estimated to be approximately 300,000 miles.

Aftermarket Parts

Little information is available on the quality of original equipment manufacturer (OEM) versus aftermarket part quality, and no information on their emission performance is available. Nevertheless, concern has been expressed that aftermarket parts are of inferior quality, are low priced, and that use of these parts leads to emission increases.

Based on information collected in this study, it appears that aftermarket part usage is not extensive - an upper limit of 15 percent was identified. According to conversations with four aftermarket suppliers, the production specifications for aftermarket parts are the same as those set by the engine manufacturers. Many of the parts manufacturers supply the same part to the aftermarket that they supply to the OEM.

Conversations with OEM's indicated that they believe the problem with aftermarket parts is one of durability, not emissions. They also indicated that some types of non-OEM parts, such as the injector or the turbocharger, may not incorporate all of the design changes for a specific engine, or that they might not distinguish between federal and California ratings. In conversations with aftermarket parts suppliers, we could find no evidence to support these assertions.

The prices charged for emission critical aftermarket parts are not consistently lower than those charged by OEM dealers. In fact, the price relationship between them varies, with several cases noted where aftermarket parts were either equal or higher in price than OEM parts.

<u>Frequency of Uprating</u>

Uprating refers to the practice of rebuilding an older engine to a newer specification, usually to increase the horsepower and/or its efficiency. An engine can usually be uprated in any of the three rebuild modes. However, some equipment changes may preclude an in-frame rebuild from uprating selected engines. Data on this subject were collected in all of the rebuild surveys. Estimates of uprating varied between fleets and rebuild shops. The fleet average estimate was 41 percent and the rebuild shop average 23 percent, with very large variations in these responses. Manufacturers estimated the activity at a lower level of 10 to 20 percent.

From an emissions perspective, uprating presents two options:

- change the engine specifications from a California to a 49-state engine and increase its emissions; or

- uprate a California engine to a new California specification and decrease its emissions.

Because of the performance advantage of a federally certified engine, in terms of both fuel economy and acceleration, there is reason to suspect that owners are motivated to uprate California engines to federal specifications. None of the rebuild shops has any incentive to keep statistics on the frequency of this occurrence. All the data collected on this subject came from the memories of shop superintendents through a follow-up telephone survey. The survey indicated that a request for uprating from California to federal specs is an infrequent occurrence. Several rebuild shops indicated that some manufacturers will not warrant a California engine that is uprated to federal certification specifications.

Modifications to Fuel Injection Equipment

All surveys collected data on this subject. Many modifications are possible. They include: increasing the fuel rate; advancing the timing; retarding the timing; replacing the fuel pump with an off spec pump (e.g., 49-state pump); use of the wrong injector spray tip; throttle delay disconnect; and incorrect injection pump calibration. Concerns about power and fuel economy were believed to stimulate high tampering rates for some of the above categories. Because of concerns about respondent honesty, questions on this subject were asked two ways: respondent experience and respondent perception of industry practice.

The perception of industry practice was always higher than shop experience. The overall average rate of fuel injection system modifications noted from in-house experience was 22 percent. High levels were noted for the following categories:

- incorrect injection timing, advance (15 percent)
- throttle delay disconnect (35 percent)
- incorrect injection pump calibration (30 percent)

These estimates are based on a review of the perception of industry practice, not in-house experience. This approach also produced a 10 percent estimate of incorrect turbocharger usage. Because the questionnaire was designed to overcome respondents' self-incrimination concerns, it is not possible to distinguish the respective contributions of rebuilding and tampering to the rates noted above.

Emissions Impact Due To Improper Rebuilds

Incorrect rebuilds cause emissions to be higher than the original zero-mile level after rebuild. They result in what is termed an "offset", an increase in emission level that is independent of mileage. This offset represents the difference in emissions improvements between properly and improperly rebuilt engines.

Fleetwide estimates of these offsets were produced by combining estimates of the emissions impact of each incorrect rebuild type with the rate of occurrence observed in the surveys. Three scenarios were developed to bound the range of possible impacts: low; base; and high.

The estimates from the base scenario indicate the emissions impact due to rebuilding can be significant. The base case increase for HC is 25 percent, and 3.4 percent for NOx. Particulate emissions,* while not explicitly calculated, are expected to increase at a rate in proportion to the increase in HC emissions. Close examination of the individual contribution of each type of incorrect rebuild indicates that:

- injection pump calibration and maladjustment of the throttle delay disconnect are responsible for 80 percent of the excess HC emissions;

- advanced injection timing is responsible for over 67 percent of excess NOx emissions.

All of the above are service items; these maladjustments can occur during routine maintenance, as well as rebuild. Excess emissions caused by incorrect equipment replacements specifically identified as occurring in the rebuild process are low, and range from less than 20 percent of the emissions increase estimated for HC and 33 percent of that estimated for NOx.

CONCLUSIONS

Remanufactured engines constitute a minor portion of California heavy-duty engine sales. The emissions of these engines are required to match the levels from their earlier certification. There is no cause for concern, from an emissions perspective, from the sales of these engines.

Heavy-duty diesel engines experience several rebuilds in their lifetime. The survey data shows that an average engine receives 4 rebuilds and travels slightly more than 1 million miles in its lifetime.

No data could be found to show that aftermarket parts increase the emissions of HDDV's. Data were collected showing that much of the prevailing wisdom about aftermarket parts is incorrect: they are made to the same production specifications as OEM parts; they are often manufactured by the same company that supplies the OEM; and they are not always less expensive.

Uprating is a frequent occurrence and offers the potential to either increase or decrease the emissions of the base engine. The limited survey data collected in the study indicate that uprating from a California to a federal specification is an infrequent occurrence;

* All diesel particulates measure less than 10 microns in diameter and are therefore in the respirable range.

therefore, no substantial emissions impact could be found from this practice.

Data collected in the survey indicate that fuel injection modifications are a frequent occurrence. Unfortunately, the survey design does not allow the distinction between injection system modifications that occur in the rebuild shop and those that occur in the field. The survey requested data on the frequency of improper modifications noted on equipment coming into the shop, as well as procedures employed in the shop. Generally, most shops denied performing improper injection system modifications but noted problems with equipment received for repair. The source of the improper modifications cannot be identified from the survey data. A much larger survey of maintenance, as well as rebuild shops, would be required to identify the source of the problem. Even then equipment modifications occurring in the field could only be estimated.

The HDDV emission impacts estimated from the survey results indicate that rebuilding can cause a significant increase in emissions. The Base Scenario produced an estimated increase of 11.86 tons/day of HC and 11.42 tons/day of NOx. The primary source of the fuel injection maladjustments causing the increase in emissions cannot be identified from the surveys. Based on numerous conversations with rebuild shops and fuel injection repair facilities, we believe that most of the injection modifications are occurring in the field, not in the rebuild shop. This leads us to the conclusion that servicing, not rebuilding, is the more significant source of excess emissions. This finding eliminated the need for recommending changes to rebuilding, reconditioning or remanufacturing practices in order to minimize increased emissions from improper procedures.