EXECUTIVE SUMMARY

DIESEL RETROFIT TECHNOLOGY AND PROGRAM EXPERIENCE

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OVERVIEW

This report provides a detailed review and analysis of diesel retrofit technology application and program planning/implementation experience in the U.S. since 2000. Information in the report is derived from two sources: 1) publicly available articles, reports, and other documents and 2) information collected directly from retrofit projects in the U.S. The literature search focus was on retrofit experience in the U.S. during the period from January 2000 to the present, supplemented with information on diesel retrofit technology and program experience in other countries since the 1990s. Over 200 documents were reviewed in preparing this report. Over 220 projects were identified throughout the U.S. Information was requested from each of them and was received from nearly two-thirds.

This report was prepared for the U.S. Environmental Protection Agency's (EPA) Office of Transportation and Air Quality, Certification and Compliance Division[1] as part of an on-going, comprehensive EPA evaluation of the diesel retrofit experience in the U.S. since the EPA's Voluntary Diesel Retrofit Program (VDRP) was established in 2000. EPA created the VDRP to promote and facilitate the implementation of voluntary retrofit programs at the state and local level in order to reduce emissions from diesel engines. The VDRP serves to complement the Agency's aggressive program to reduce particulate matter (PM) and oxides of nitrogen (NOx) emissions from new on-road and nonroad diesel vehicles and equipment by up to 90% or more over the next decade. EPA has set a long-term goal of retrofitting, rebuilding, repowering, or replacing the estimated 11 million existing diesel engines in the U.S. by 2014. EPA defines the term "retrofit" broadly to include technology retrofits, fuel-based strategies, early vehicle/equipment retirement, engine rebuilds, repowers and operations-based strategies such as reduced idling. This report focuses primarily on technology- and fuel-based strategies, but information on other strategies is included in those instances where they were used in combination with retrofit technology and fuel strategies.

This report is designed to serve both as a reference tool on U.S. retrofits technologies and programs for interested parties, and to document important experience gained and valuable lessons learned. This experience and lessons learned will assist those considering retrofit initiatives to effectively assess, plan, implement, and evaluate retrofit programs. EPA will also use the information provided in the report, combined with other evaluations, including an in-use testing program for verified technologies, to insure the continued effective implementation of the VDRP.

INTRODUCTION AND SUMMARY OF FINDINGS

Section 1.0 provides background discussion on EPA's ongoing evaluation of retrofit experience and details the scope of the report. This section also provides a summary of findings, including information on available retrofit technologies, information on U.S. retrofit projects by technology and applications, and highlights of lessons learned.

[1] The name of the EPA Certification and Compliance Division is expected to change.

RETROFIT TECHNOLOGY EVALUATION

Section 2.0 of the report reviews the full range of experience with technology- and fuel-based retrofit strategies including: diesel oxidation catalysts (DOCs), passive and active, high- and low-efficiency diesel particulate filters (DPFs), fuel-borne catalysts (FBCs), lean NOx catalysts (LNCs), selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), low-pressure exhaust gas recirculation (EGR), closed crankcase ventilation (CCV) systems, ULSD, biodiesel, emulsions, fuel additives, and others. Information reported on each retrofit technology focuses primarily on engine applications; retrofit product performance; durability; cost; fuel requirements; installation requirements and experience; recommended technology maintenance vs. actual maintenance experience; overall operating experience; warranties; failure rates; causes and any documentation of failures; and action taken, if any, to correct problems. For fuel-based strategies, information is provided on fuel properties, specifications, manufacture/ blending, delivery, storage, costs, any problems, and actions taken, if any, to correct problems.

Retrofit technology programs can be grouped into two broad categories. The first type is designed to demonstrate the applicability, performance, and emission reduction characteristics (frequently with extensive emission testing) of a given technology. Reports found in the literature tended to focus on these technology demonstration-type programs, and this provided useful examples of "lessons learned". The second type is designed to apply the technologies with the primary goal of achieving emission reductions to improve air quality. Most of the projects in the U.S. in which data was collected fit into this second category, and typically did not include emission testing. Rather, the program relied on other means of quantifying emissions reductions (e.g. developing emission reduction estimates from EPA- or CARB-verified emission reduction levels for a given technology).

All of these technology- and fuel-based strategies generally deliver the operating and emission reduction results that are claimed for them, but the levels of emission control achieved in some cases was highly dependent on the emission test cycle used. In those instances in which problems did occur, several factors were identified. In some cases, problems occurred when technologies were extended to applications that were marginal including programs specifically designed to evaluate the limits of the technology. In other cases, technical problems resulted because the sulfur levels in the fuels were too high for successful application of the technology or the technology was applied incorrectly. This situation was well illustrated in several projects involving catalyst-based DPFs. In other cases, there were mechanical problems, such as the failure of retrofit equipment mounting brackets. In most instances where technological problems occurred, corrections were identified and implemented in subsequent projects. In still other cases, problems could be traced directly to insufficient or inadequate knowledge on the part of users or program creators/administrators. As with any other new or unfamiliar technology, successful use requires an understanding of product function, proper installation and use, attention to recommended product selection criteria, and operating and maintenance requirements. Problems identified with fuel-based retrofit strategies were mostly related to a lack of measures to prevent misfueling (using low sulfur fuel instead of ULSD for DPF-equipped vehicles), and more generally, a lack of fuel quality control measures (in both the fuel itself and local storage/dispensing equipment) that resulted in vehicle performance problems of various types.

RETROFIT PROGRAM DESIGN, PLANNING, IMPLEMENTATION AND EVALUATION

Section 3.0 discusses retrofit program design, planning, implementation, and evaluation issues. Retrofit programs fall into two major categories: mandatory programs and voluntary programs. Each type of program structure has its advantages and disadvantages. For example, mandatory programs have the benefit of generating emission reduction benefits that are more easily quantifiable, more "permanent" and enforceable than those of some voluntary programs. Conversely, voluntary programs are dependent on prospective technology users to "come forward" and offer to operate their vehicles or equipment with retrofit products, without the potential for having to face any penalties for noncompliance. Information from the available literature and retrofit projects suggests that each form of program structure seems to have been successful, even though each type has needed to address various planning and implementation issues which are discussed in the report.

The report reviews the experience with mandatory programs in the U.S. (e.g., California Diesel Risk Reduction Plan, DRRP), as well as programs in Switzerland, Hong Kong, Sweden and elsewhere. Factors to consider when adopting a mandatory program are also discussed in the report.

For voluntary programs, information is provided in the report on project descriptions and objectives, partners, sources of funding, outreach, project planning, implementation, and evaluation elements. The project objectives, scope of the projects (e.g. number of vehicles/equipment), sources of funding, degree of technical support provided, and method of evaluating the project varied considerably. Examples of different types of voluntary programs are provided in the report.

The U.S. retrofit programs examined for this study involved a wide variety of vehicles and equipment, including school buses, transit buses, utility vehicles, delivery vehicles, refuse trucks and nonroad equipment. Funding sources included Federal, state, and local governments, enforcement settlement funds, and private sector funding.

RETROFIT TECHNOLOGY AND PROGRAM EXPERIENCE LESSONS LEARNED

A number of successful retrofit programs have been completed or are underway that have used emerging or more established retrofit technologies. As experience grows with retrofit technology and program issues, valuable lessons learned are emerging that will prove extremely helpful as future retrofit initiatives move forward. Section 4.0 of the report identifies a number of lessons learned regarding both the technologies and programs. In some cases, these lessons learned are technology- or fuel-specific, while in other instances they are more universally applicable. These lessons learned cover such topics as:

- ***Retrofit Technology- and Fuel-Based Strategies***
    - Accessing and estimating emissions reduction for a given retrofit technology and vehicle/equipment application.
    - Vehicle/equipment applications and experience.
    - Selecting the appropriate retrofit technology strategy.

  - Selecting the appropriate fuel-based strategy.
  - Retrofit product delivery.
  - Pre-installation actions, installation, vehicle/equipment and technology maintenance, and operation.
  - Estimating fuel economy impacts.
  - When retrofit technology monitoring equipment should be employed.
  - Fuel quality, transport, handling and storage.
  - Vehicle/equipment preparation when switching to a fuel other than conventional on-road or nonroad diesel fuels.

- ***Retrofit Programs***
  - Selecting the appropriate vehicle/equipment application for the technology/fuel used.
  - Technician and operator education and training.
  - Public outreach and education.
  - Project funding.
  - Project implementation.
  - Retrofit product procurement issues.

CONCLUSIONS

Retrofit technology optimization and applications continues to advance at a rapid rate both with established technologies such as DOCs and DPFs as well as with emerging technologies such as flow-through filters, SCR, low-pressure EGR, LNC and CCV technologies. On occasion, issues have arisen in some U.S. programs during the period covered by this report due to such factors as incorrect application of technology, misfueling or fuel contamination, mechanical failures, and problems with monitoring equipment. These issues are becoming better understood and field fixes are being developed and employed to reduce the instances of such problems. Similarly, experience with fuel-based strategies is rapidly advancing and some of the initial issues (e.g., fuel contamination, failure to meet specifications, blending, and storage) are now better understood, and appropriate precautions have been identified and are being implemented. Today, a wide range of retrofit strategies is available for nearly any vehicle or equipment application. Care must be taken, however, to match a given retrofit strategy with the specific engine, vehicle/equipment type, operating mode and duty cycle.

The number of retrofit programs in the U.S. has dramatically increased in the U.S. since 2000 when EPA created the VDRP. The growing popularity of these programs is based on several factors, including: the need to find additional methods for improving air quality (beyond the establishment of more stringent emission standards that are applied to newly-manufactured future engines and vehicles), greater knowledge and concern about the health effects of vehicle exhaust constituents, availability of a variety of retrofit products from reputable product suppliers and meaningful levels of financial incentives/support. A growing body of retrofit program and project experience is being developed. Much of this experience, however, has not been previously reported extensively or documented. The retrofit technology application and retrofit program experience documented in this report should provide valuable guidance to those pursuing retrofit strategies in the future.

The current level of interest for initiating retrofit programs is beginning to far exceed the available funding for such projects. A major future challenge in advancing retrofit initiatives is to make available the funding and other incentives needed to enable these projects to go forward. A second challenge is to insure that adequate, effective and competent technical support is available for retrofit projects, particularly at the technology selection, vehicle/equipment selection, product installation and operational phases.